Greater Vancouver Regional District Cautions, Warnings and Triggers:

A Process for Protection of the Receiving Environment

Volume I – Main Document

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DEDICATION

In memory of Dr. Brian Wilson, whose vision provided the encouragement to bring us to where we are today.

PREFACE

The Greater Vancouver Regional District (GVRD) has committed to the principle of managing liquid waste in a sustainable manner that protects and enhances the receiving environment in a cost effective manner. This commitment is detailed in the District's Liquid Waste Management Plan (LWMP). The LWMP process is mandated by the Province of British Columbia and is designed to ensure an integrated, local approach to making conclusive and informed liquid waste management decisions.

Upon approval of the LWMP, the Minister also required that the GVRD "Develop the environmental 'triggers' used in the monitoring process by January 31, 2004, recognizing that the environmental monitoring process in the LWMP is based on discharge indicator trend analysis such that action will be implemented before Water Quality Objectives or other criteria are met or exceeded". A key component of the Plan (Commitment C4 of the LWMP) involves monitoring, assessing and forecasting to evaluate effects of GVRD's liquid waste discharges. Monitoring is vital in providing information to effectively manage liquid waste discharges on a regional basis.

If the results of the monitoring indicate effects in the receiving environment, the GVRD will respond via the process outlined in the LWMP. This document outlines an overall indicators, cautions, warnings and triggers framework for assessing the need for action based on receiving environment effects. The process provides information critical in the effective management of liquid waste discharges on a regional basis, and furnishes a means of establishing priorities based on the science of risk management.

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EXECUTIVE SUMMARY

To address Condition 2 of the Ministry of Water, Land and Air Protection's approval of GVRD's Liquid Waste Management Plan in April of 2002, the District has committed to developing a framework for environmental cautions, warnings and triggers to be used in conjunction with a scientifically-based receiving environment monitoring program. The framework forms the foundation of a process for indicating ecological changes prior to adverse environmental effects occurring due to GVRD liquid waste discharges to the receiving environment.

The cautions, warnings and triggers framework is primarily a weight-of-evidence approach. Indicators have been selected for different environmental compartments. Based on the level of the indicator outcomes, certain responses are defined. Options for managing the defined responses will be developed by the District and member municipalities and assessed according to ecological, social and economic criteria.

The adaptive and dynamic nature of this framework provides the flexibility necessary for the introduction of new and relevant information that may develop through other studies and initiatives. It is also anticipated that as the scientific knowledge develops the process will evolve to accommodate this new science pertaining to sensitive monitoring tools, persistence and environmental fate of contaminants of concern, level and type of risk expressed by certain chemicals in the environment, mode of transport within the food chain, interactions within the environment, and the identification of emerging issues. A process such as this is an open process that must be sensitive to the changing scope of scientific knowledge and consequently be dynamic and adaptive in nature.

This document provides discussion of the application of the cautions, warnings and triggers approach to each of three primary compartments of the aquatic environment, including:

- Water Column – (Chapter 2)
- Sediment – (Chapter 3)
- Biota – (Chapters 4 and 5):
    - Benthos – (Chapter 4)
    - Higher Trophic Levels – (Chapter 5)

Water Column

Indicator substances used to assess achievement of water column caution, warning and trigger levels include conventional constituents, metals and trace organics. The status of indicator substances is determined by comparison with selected levels. These levels are based on Provincial Water Quality Guidelines and site-specific Water Quality Objectives and are summarized below.

Water Column Caution Levels:

> The substance concentration outside the Initial Dilution Zone is greater than or equal to 60% of the relevant Provincial Water Quality Guideline value

Water Column Warning Levels:

> The calculated substance concentration at the Initial Dilution Zone boundary is greater than or equal to 60% of the relevant Water Quality Objective value

Water Column Trigger Levels:

> The measured substance concentration at the Initial Dilution Zone boundary is greater than or equal to 80% of the relevant Water Quality Objective value

Sediment

The use of a Sediment Quality Index has been shown to be a reasonable sediment indicator sensitive to changes in sediment quality and has been developed as an appropriate indicator tool. It has been demonstrated that the Index can be used to track temporal and spatial trends. These trends can then be correlated with benthic health data to determine the relevance of, and contribution from, a given contaminant source.

Provincial Water Quality Guidelines and site-specific Water Quality Objectives will be used in assessing sediment quality in calculating the Sediment Quality Indices. These index values will be used to identify a caution (guidelines) or warning (objectives) status only, because exceedance or attainment of guidelines or objectives does not necessarily indicate either an effect or the lack of an effect. Effects, or the lack of them, can only be determined by biota surveys which are directly indicative of the health of the environment. A weight-of-evidence approach is thereby adopted.

Proposed Sediment Quality Index values are calculated annually for individual and groups of benthic monitoring stations. Index values are compared to a caution or warning level that is based on a range of two standard deviations around an average annual Sediment Quality Index value. If the caution or warning level were to be exceeded on any one or multiple stations, the substances comprising the index would be analyzed to identify any specific substances causing the increase in the index. Should the subsequent year's sampling program identify a further or sustained increase in the index values compared to the applicable caution or warning levels, an investigation identifying the cause of the increase would be carried out including assessment of its level of attribution to the potential contaminant source.

Benthos

Benthic cautions, warnings and triggers have been developed for the Strait of Georgia and Burrard Inlet. Based on experience with these, and consideration of adjustments specific to the given environments, extension of the benthic indicator approach to the Lower Fraser River is intended.

Based on an ecological assessment of the effects in the Iona study area and a rigorous monitoring program, it was concluded that biotic effects are evident but of relatively minor ecological concern. Observed biotic effects within the Iona study area are moderate to mild and can be well delineated spatially. In addition, benthic conditions appear to have remained stable in the Iona receiving environment over the period of 2000-2003. Data from 1991 and 1995 suggest that this stability has been inherent in the area since shortly after the commissioning of the deep-sea outfall.

In Outer Burrard Inlet, identifying a footprint for discharge-related solids deposition has not yet been possible. The lack of any evidence of the discharge in the projected maximum deposition areas suggests that benthos are not adversely affected by the Lions Gate discharge.

Based on detailed work carried out in the Iona study area, combined sets of indicators have been identified for cautions, warnings and triggers that can be used to isolate the effects of wastewater particulate deposition and to assess ecological health of the receiving environment. Since sediment organic enrichment and related geochemical changes appear to cause most of the biotic effects observed, warning and trigger levels are based on biotic indicators coupled with reliable geochemical indicators of sediment organic enrichment, and with wastewater indicators. This combination should prevent mistaking wastewater effluent effects for any confounding influences in the area.

Cautions, warnings and triggers are based on the 95th percentile of the cumulative frequency distribution for relevant indicators for a given zone over time. Since a variability of up to 20% in sampling precision is considered acceptable for benthic marine grab samples, a given sample must fall more than 20% outside the limit of the 95th percentile for the range to be considered a reliable and "real" change in the condition of the indicator in question. Caution, warning and trigger levels for Iona incorporate temporal and spatial variability measured over four years (2000 to 2003). However, caution, warning and trigger levels for Outer Burrard Inlet are derived based on the existing 95th percentile ranges for the stations sampled in the first relevant monitoring survey.

Cautions provide early indication of changes in background reference conditions in the selected reference stations. Caution levels apply when any new reference samples fall outside plus or minus 20% of existing 95th percentile ranges for reference zones for a suite of relevant indicators. Warnings apply to affected zones in the Iona receiving environment. Because existing stations monitored in Burrard Inlet are considered to be in "reference" condition, warnings for enriched or impoverished zones are not applicable.

Warnings apply for selected indicators which vary more than 20% from the 95th percentile range for any 3 replicate samples over a two year sampling period. The specific warning ranges vary for different pre-determined effect zones identified in the historical monitoring data; these zones include moderately impoverished, low impoverished or biotically enriched.

Trigger levels are not statistically derived, but based on best professional judgment and experience in other jurisdictions with similar types of organic enrichment effects. Trigger indicators and levels are designed to prompt a response prior to projected environmental degradation. Triggers for all effect zones are based on change in relevant indicators from historical conditions, past warning levels, to plus or minus 50% of reference ranges (based on the 95th percentile range for a given year) for any 3 replicate samples over 2 sampling years. All caution, warning and trigger levels must be reached concurrent with significant increases in AVS and 4-nonylphenol.

Currently, a benthic monitoring approach called the Benthic Index of Biotic Integrity is being assessed as a potentially useful descriptor of small stream health within the GVRD.

Higher Trophic Levels

Tissue residue objectives apply where Water Quality Objectives have been set for a given area, and are generally defined for fish although the guidelines upon which they are based frequently state that they apply to human consumption of edible tissue from fish and/or shellfish. Where Water Quality Objectives do not exist, guideline values will be considered. Unequivocal linkages between tissue contaminant concentrations and specific discharges cannot generally be established. Consequently, tissue residue values are allocated cautionary status due to their importance in establishing health at higher trophic levels, and will be considered in the cautions, warnings and triggers framework.

Responses to Cautions, Warnings and Triggers

The consequence of reaching or exceeding caution, warning or trigger levels is that certain responses are defined as arising out of an exceedance. These responses are in keeping with the nature of the exceedance. Consequently, in moving from warnings to triggers we have a graduated set of responses. These are:

Caution Responses:

- *Caution Response 1*: Identification of cause (e.g., sampling or processing error, increased organic loading, natural region-wide phenomena, outside existing or new effects, etc.);
- *Caution Response 2:* If liquid waste discharge is source – risk assessment of temporal trend and determination of response need;
- *Caution Response 3:* Intensified sampling to confirm identification of cause and predict progression towards Water Quality Guideline.

Warning Responses:

- *Warning Response 1*: Identification of cause (e.g., sampling or processing error, increased organic loading, natural region-wide phenomena, outside existing or new effects, etc.);
- *Warning Response 2*: If liquid waste discharge is source – risk assessment of temporal trend and determination of best means to respond;
- *Warning Response 3*: Intensified sampling to confirm identification of cause and predict progression towards trigger status.

Trigger Responses:

- *Trigger response 1*: Identification of cause (e.g., sampling or processing error, increased organic loading, natural region-wide phenomena, confounding effects, etc);
- *Trigger response 2*: If liquid waste discharge is source, review mitigation options with the Environmental Monitoring Committee, sanction with the GVRD and present to the Province;
- *Trigger response 3*: Implement approved mitigation.

The above process has been developed within the context of the commitments outlined in the District's Liquid Waste Management Plan. It is intended to be a predictive and adaptive process which will allow the GVRD to respond proactively to issues of environmental quality. To ensure involvement of the relevant stakeholders, an Environmental Monitoring Committee was structured as part of the process in the Liquid Waste Management Plan. This science-based Committee reviews the various monitoring designs and initiatives and provides critique and recommendations. The Committee also brings forward issues to the GVRD based on work being done elsewhere. Through integration of the efforts of the GVRD and its member municipalities and those within the federal and provincial governments, the universities and their associates, a process unique in Canada has been developing on the West Coast. This process is consistent with the GVRD's commitment to sustainability as per the Sustainable Region Initiative.

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AET	Apparent Effects Thresholds
AVS	Acid Volatile Sulphide
AWQG	Approved Water Quality Guidelines
B-IBI	Benthic Index of Biotic Integrity
BIEAP	Burrard Inlet Environmental Action Program
BMP	Best Management Practices
CCME	Canadian Council of Ministers of the Environment
CEPA	Canadian Environmental Protection Agency
CEQG	Canadian Environmental Quality Guidelines
CRD	Capital Regional District
CSO	Combined Sewer Overflow
DL	Detection Limit
DO	Dissolved Oxygen
EC	Environment Canada
EEM	Environmental Effects Monitoring
EMC	Environmental Monitoring Committee
EPA	US Environmental Protection Agency
EQO	Environmental Quality Objectives
ERL	NSTP Effects Range Low
ERM	NSTP Effects Range Median
GVRD	Greater Vancouver Regional District
GVS and DD	Greater Vancouver Sewerage and Drainage District
HPAH	High Molecular Weight Polycyclic Aromatic Hydrocarbons
HQ	Hazard Quotient
IDZ	Initial Dilution Zone
ISQG	CCME Interim Sediment Quality Guidelines
LPAH	Low Molecular Weight Polycyclic Aromatic Hydrocarbons
LWMP	Liquid Waste Management Plan
MELP	Ministry of Environment, Lands and Parks
MWLAP	Ministry of Water, Lands and Air Protection
NP	4-Nonylphenol
NSTP	US National Status and Trends Program
NWRI	National Water Research Institute
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PEL	CCME Probable Effects Limit
PWQG	Provincial Water Quality Guidelines
SD	Standard Deviation
SDI	Swartz Dominance Index
SQG	Sediment Quality Guideline
SQI	Sediment Quality Index
SQV	Sediment Quality Value
TBT	Tributyltin
TEF	Toxicity Equivalent Factors
TEL	Threshold Effects Level

TEQ	Toxicity Equivalent Quotients
TOC	Total Organic Carbon
TOV	Total Observed Volume
TV	Tissue Values
USEPA	US Environmental Protection Agency
WQO	Site specific Water Quality Objectives
WWQG	Working Water Quality Guidelines
WWTP	Wastewater Treatment Plant

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CHAPTER 1.

INTRODUCTION

1.1 OVERALL OBJECTIVES

"Creating our Future" – an agenda for regional and local action – was adopted by the GVRD Board in 1990 and readopted in 1993 and 1996 as a founding statement of liquid waste management in the region:

> ***The region will manage waste in a manner that enhances environmental quality: Greater Vancouver will be a place where human activities enhance rather than degrade the natural environment, where the quality of the built environment approaches that of the natural setting, where characteristic outstanding livability and environmental quality are protected.***

GVRD's environmental management process has been developed as a means of assessing incremental influences from the District's municipal liquid waste discharges, and a means of focusing management on actual ecosystem protection to ultimately prevent adverse ecological effects to the receiving environment. The process is founded upon the development of caution, warning and trigger indicators, which are indicative of municipal liquid waste effects that can indicate adverse ecological changes.

Fundamentals of GVRD's caution, warning and trigger framework are not only science based, adaptive, site specific, statistically defensible and holistic, but also sensitive and predictive to ensure that management is based on environmental protection now and in the future. Sensitive tools will be used to measure change in condition of the receiving environment, assess rate of change and compare with reference or background values so the degree of change can be adequately characterized. The process then facilitates the implementation of mitigating action(s) before objectives, guidelines or other criteria are met or exceeded.

A broad suite of indicators will be used in the indicator trend analysis, and the dynamic nature of the process permits the incorporation of new indicators or tools as they are developed. The process thereby permits the District and its member municipalities to tailor plans for managing liquid waste within the constraints of each area's unique environmental, economic and social conditions. The monitoring process described in this document provides a framework for an ongoing dynamic process of research, monitoring, assessment and forecasting, tactical and operational planning, and implementation involving all levels of government working in partnership. Ongoing monitoring, assessment and review ensure that this process for protection of the environment is continuous, and capable of measuring progress towards clearly defined goals and objectives.

1.2 RATIONALE FOR THE APPROACH

The cautions, warnings and triggers process is primarily a weight-of-evidence approach. Cautions, warnings and triggers have been set for the selected indicators in the different compartments based on an understanding of the local systems. The context in which this process has been developed relates to the linkages between human activity and the biological responses and changes that are of concern. Biological "criteria" may be more appropriate than physical or chemical criteria in establishing the link between human activity and its impacts on the receiving environment. Understanding of change and consequently related effects or impacts is best served by interpreting biological response in conjunction with physical and chemical changes. Specifically, an understanding of the extent and magnitude of discharge effects on the receiving environment requires interpretation of physical, chemical and biological parameters in water column, sediment and biotic compartments of the receiving environment.

1.3 INDICATOR SELECTION PROCESS

1.3.1 Overview

The monitoring framework described in this document has been developed to provide a means of assessing effects of the District's municipal liquid waste discharges on the receiving environment, and to ultimately avoid adverse ecological effects to the environment. This framework is founded upon the development of caution, warning and trigger indicators, which are indicative of wastewater or stormwater effects that may suggest adverse ecological changes. In order to be useful tools in the characterization of receiving environment effects directly related to liquid waste discharges, all selected indicators must meet certain criteria. These criteria determine how specific the indicator is to the wastewater or stormwater discharge in question, how it is affected by ambient or confounding conditions in the region, and how useful it is in illustrating the relative health and assimilative capacity of the receiving environment in question.

1.3.2 Indicator Selection

Prior to indicator selection, the character and extent of receiving environment effects, which are ecologically significant and potentially hazardous to ecosystem health, must be clearly defined. The types and characteristics of effects of concern related to municipal liquid wastes must be identified and prioritized, the natural variability in the area of interest for each indicator must be adequately understood and characterized and potential confounding influences outside the discharge area must be considered. Those indicators selected must be consistent, attributable to discharge effects with reasonable confidence and limited in spatial and temporal variability.

Appropriate criteria for the selection of caution, warning and trigger indicators include but are not limited to existing guidelines such as Water Quality Objectives (WQO) or Canadian Council of Ministers of the Environment (CCME) guidelines, toxicity data and statistical variability. Additional ecological considerations may include the capability of the indicator to reflect shifts in community dynamics and potential to affect higher trophic levels, local fisheries and human health.

Most regulatory agencies define ecosystem health as some proportional deviation from "normal" or "reference" conditions. Therefore, in order to set benchmarks, the temporal and spatial scale of variability expected in natural "present-day" conditions must be determined – undoubtedly, a complex and difficult task. Selecting useful caution, warning and trigger indicators must then be preceded by identification of the types and spatial extent of effects related to the discharge in question. That is, the concepts of reference or background variability and "exposure indicators" must first be understood and quantified.

"Exposure indicators" provide a context of the spatial extent and magnitude of receiving environment exposure to the discharges, and are therefore critical in the trigger framework. The selection of indicators depends on a number of factors including reference ranges, overall consistency, potential for influence from confounding factors, ecological relevance to ecosystem health and overall recognition by other jurisdictions. Exposure indicators must reliably indicate a specific and significant ecological response caused by exposure to the discharge in question.

Cautions, warnings and triggers must therefore be based on exposure indicators, which ultimately facilitate recognition and assessment of change from reference or background conditions. By definition then, all warning and trigger indicators must be linked to the discharge in question. If this link cannot be made, the indicator would ultimately have no useful meaning in the development of this monitoring framework. In the absence of widely accepted guidelines for determining environmental impacts from a given stressor, all impacts must be assessed relative to what is considered normal for the environment in question.

Substances chosen as indicators for the development of cautions, warnings and triggers are monitored in both GVRD wastewater discharges and the ambient (background) environment. In order to have utility in the monitoring framework, these substances must be expected at measurable levels in discharge. Furthermore, these substances must not have confounding factors which would complicate the process of accurately determining the discharge contribution to a given measured environmental effect.

Following is a brief discussion of the specific indicator levels used in the discharge indicator trend analysis forming the foundation of GVRD's monitoring process, including their unique selection criteria:

Caution Indicators

Cautions provide notification relative to spatial and/or temporal change in ambient or reference conditions outside a pre-determined margin set by sampling methodology. Ultimately, a caution indicator dictates the need for further investigation to determine whether the effluent in question can be linked to the change, and to characterize and exclude any confounding influences. Potential causative pathways and trends must be assessed, and increased monitoring will determine the need for further mitigating actions.

Ambient cautions are only applied to the framework in a general sense, and are used to illustrate that a certain condition has been detected in the surrounding environment. These indicators are representative of ecosystem health, but do not immediately lend themselves to direct linkage to the discharge in question. An example would be fish and mammal health. A detected change is inherently important and may instigate further investigation, but immediate direct linkage to a causative factor related to the discharge is beyond the current scope of this monitoring framework. However, should a caution level for an ambient indicator be reached, additional scrutiny would be placed on the other indicators with respect to approaching a caution, warning or trigger level. Again, it is important to note that a causative link may not be easily identified.

Cautions are based on deviations from historical reference conditions, and provide a means of continuously assessing the performance of reference levels for indicators. They are a means of recognizing unexpected (natural and anthropogenic) influences external to the discharge, changes in sampling or analytical methodology for monitoring programs or long-term natural environmental or biological cycles. The ongoing Ambient Monitoring Programs in the Strait of Georgia and the Fraser River provide further validation of reference ranges.

Cautions proposed for the water column are based on Provincial Water Quality Guidelines, which would apply to the initial dilution zone boundary waste discharges and to the ambient receiving environment.

Warning Indicators

Warnings indicate change in substance level or biota community structure of potential concern relative to the current condition of the given receiving environment, which can reasonably be attributed to the discharge in question. A warning shows an exposure, which may in the future be associated with an ecological change of concern. This exposure is connected to a WQO or to an observed benthic effect. Exceedance of a warning level initiates intensified sampling and monitoring to confirm cause, to predict progression towards trigger status and to assess the potential need for actions to slow, stop or reverse the observed trend.

Complete confidence in the warning level is not required; warning levels are not considered immediately detrimental or indicative of ecological degradation. Reaching or exceeding a warning level initiates extensive investigation of the cause before action is taken. A warning event may be initiated by a relative change in environmental conditions without clear indication that a negative environmental impact will occur. Therefore, changes that initiate warning events may be within the assimilative capacity of the environment and may therefore be indicative of a more or less stable condition. That said, however, the trend of change in a direction that may in the future become detrimental constitutes the warning. Ongoing monitoring may be sufficient to track the warning indicator, or more intensive monitoring may be implemented to adequately characterize the trend of change and predict progression toward trigger levels.

Trigger Indicators

Triggers indicate a measured substance level on biota community structure relative to reference conditions, but prior to reaching an ecologically deleterious condition related to the discharge. Trigger levels are based on negative changes beyond warning levels in the receiving environment, ultimately showing a trend leading to environmental degradation in the foreseeable future and therefore harbouring pressing ecological imperative. These levels are deemed threshold and when reached, prompt intensive study to identify cause and ultimately to assess mitigating options. Unlike a warning event, a trigger event clearly implies that an unacceptable environmental impact is likely to occur.

Triggers therefore comprise a very limited subset of warning indicators, and by definition must be more limited and rigid. Trigger levels will ultimately prompt mitigating actions, some of which may have far-reaching societal, environmental and economic implications; therefore, indicator selection must be extremely reliable and supported by considerable monitoring precedent. The criteria for selection of trigger levels must therefore be the most carefully conceived of all indicator levels, and always overtly related to the discharge in question.

1.3.3 Confounding Influences

Based on monitoring results, a number of potential caution, warning and trigger indicators have been identified for the receiving environments in the vicinity of the various GVRD liquid waste discharges. The presence of confounding influences in the urbanized and industrial areas near the discharge receiving environments dictates that isolated use of exposure indicators can be questionable in the determination of cautions, warnings and triggers. Geochemical and biotic indicators must therefore be linked with concurrent wastewater or stormwater specific indicators for use as cautions, warnings and triggers.

Once indicators have been identified and corresponding caution, warning and trigger levels set, the elimination of natural or region-wide phenomena as the causative factor is critical. This may be accomplished by examining change to reference and/or ambient conditions in that year and by assessing region-wide biotic, geochemical, climatic or oceanographic phenomena using scientific data from Ambient Monitoring Programs.

1.4 GUIDELINES AND OBJECTIVES

Guidelines and objectives can be set for physical, chemical or biological characteristics of water, sediment or biota. In general (and specifically for water), guidelines have been used in developing caution levels, while objectives have been used in developing warning and trigger levels. The approach to using guidelines and objectives for water column, sediment, benthos and higher tropic caution, warning and trigger levels varies as a result of the nature of the indicator (cf. Chapters 2, 3, 4 and 5, respectively). The guidelines and objectives used in this approach are summarized below.

1.4.1 Water Quality Guidelines

The BC Ministry of Water, Land and Air Protection (MWLAP) have developed Water Quality Guidelines (PWQG) to protect six major water uses: Drinking Water, Aquatic Life (freshwater, estuarine, and marine), Wildlife, Recreation and Aesthetics, Agriculture (Irrigation and Livestock Watering), and Industrial (e.g., Food Processing Industry) (MELP, 1998a, MELP, 1998b). PWQG apply throughout the province and provide the benchmarks for the assessment of water, sediment and fish tissue quality. However, PWQG do not take into account local environmental conditions, and as a result, natural conditions may potentially exceed some guidelines.

1.4.2 Water Quality Objectives

Water Quality Objectives (WQO) are derived from the PWQG and consider local water quality, water uses, water movement, waste discharges and socio-economic factors of the specific surface water body. WQO can be physical, chemical or biological characteristics of water, sediment or biota. However, as is the case with PWQG, WQO do not take into account all local environmental conditions at all times, and as a result, from time to time, natural conditions may potentially cause some WQO to be exceeded.

Within the GVRD area, WQO have been established for (Figure 1):

- Fraser River from Hope to Sturgeon and Roberts Banks and its tributaries; Kanaka Creek, Burnette River, Coquitlam River, and Pitt River (Swain, *et al.*, 1998);
- Boundary Bay and its tributaries; the Little Campbell River and its tributaries; the Serpentine River and the Nicomekl River (Swain and Holms, 1988); and,
- Burrard Inlet (Nijman and Swain. 1990).

1.4.3 Development of New or Revised Water Quality Objectives

Commitment C1 of the GVRD's Liquid Waste Management Plan (LWMP) (GVRD, 2001) outlines a collaborative process for developing new or revised WQO for water bodies within the GVRD. Commitment C1 states:

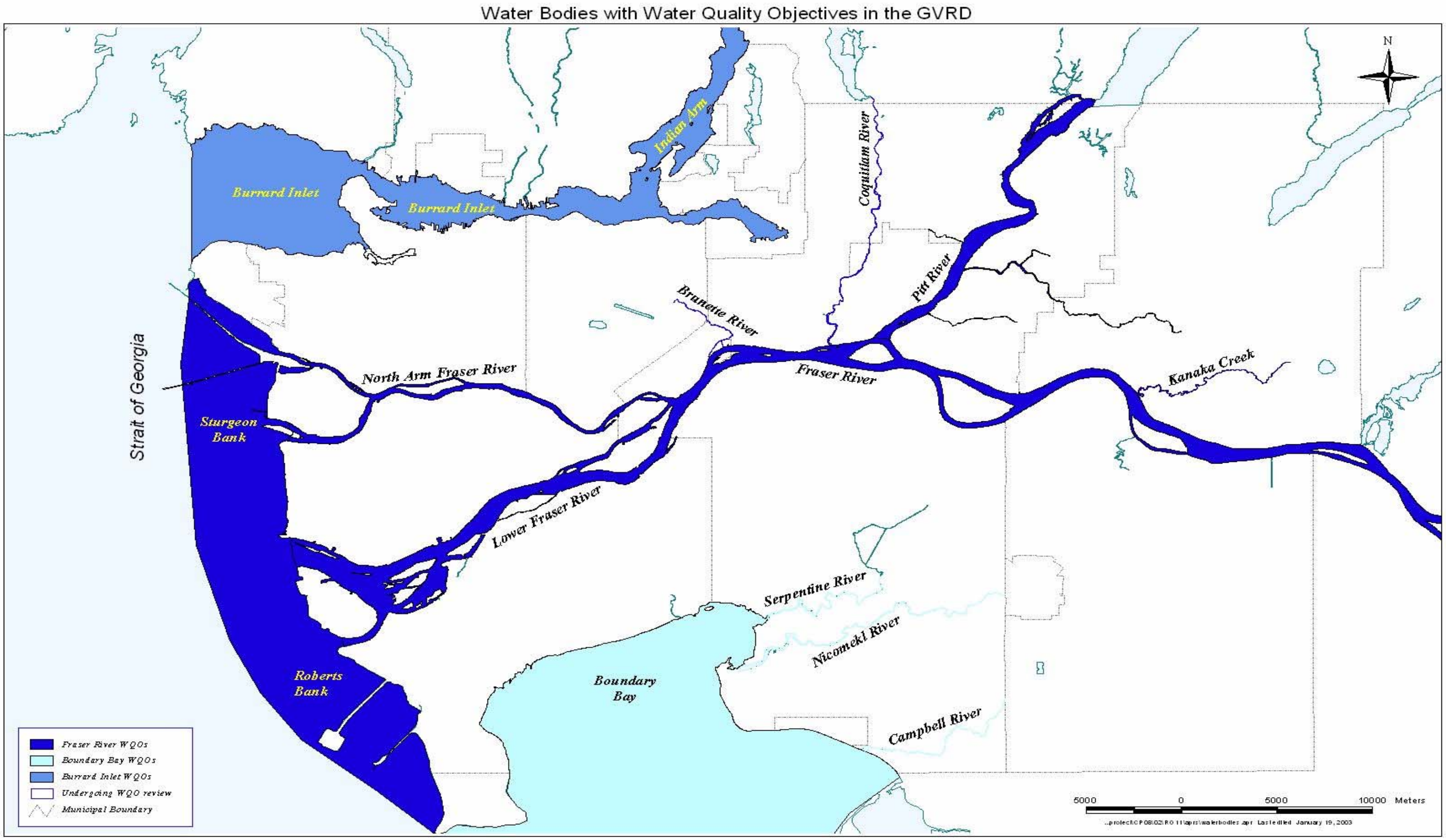
> *"C1. Official Designation for Water Uses*
>
> *The District and municipalities will take an active role in providing information to the Ministry of Environment, Lands and Parks (MELP) so that appropriate water uses receive official designation from MELP through a consultative process for each of the major waterbodies within the region. A review of a designated water use may be initiated by the District or a member municipality. The consultative process will follow Track 1 – Setting Guidelines from Principles as documented in the Ministry of Environment, Lands and Parks Guidelines and Standards Procedure, dated October 7, 1997. The process as outlined in Track 1 requires the preparation of a draft report by the Ministry.*
>
> *The following process will apply to local government participation during the preparation of the draft report to be prepared by the Ministry under the Guidelines and Standards Procedure:*
>
> *1. The Ministry will advise the District and its member municipalities, in writing, when a water use or water quality objective initiative is commenced.*
>
> *2. The Ministry will develop the scope of work for their draft report in consultation with the Environmental Monitoring Committee. The Ministry will review the draft report*

work progress with the Environmental Monitoring Committee on a regular basis. The Environmental Monitoring Committee will play an active role in the development of the report and cost implications to the District and member municipalities will be provided for inclusion in the report.

3. The cost and benefit of designated water uses, or proposed changes to designated water uses, and their associated water quality objectives will be fully documented in the draft report and the GVRD Board and municipal councils will have the opportunity to review and comment on the draft report."

Currently, an assessment to develop a bacteriological Water Quality Objective is being undertaken for False Creek, east of Sunset Beach.

Figure 1. Water Bodies with WQO in the GVRD



1.5 GVRD'S LIQUID WASTE DISCHARGES

There are five wastewater treatment plants (WWTP) in the Greater Vancouver Regional District (Figure 2). The Iona Island and Lions Gate WWTPs provide primary treatment, and discharge to the marine environments of Georgia Strait and Outer Burrard Inlet, respectively. The Annacis Island, Lulu Island and Northwest Langley WWTPs provide secondary treatment and discharge into the Fraser River.

The Iona WWTP serves the City of Vancouver and parts of the Cities of Richmond and Burnaby. The discharge occurs through a long deep-sea outfall with twin diffusers approximately 7 km from the shore and at a depth of 90 m in the Strait of Georgia. The average discharge is approximately 600 MLD.

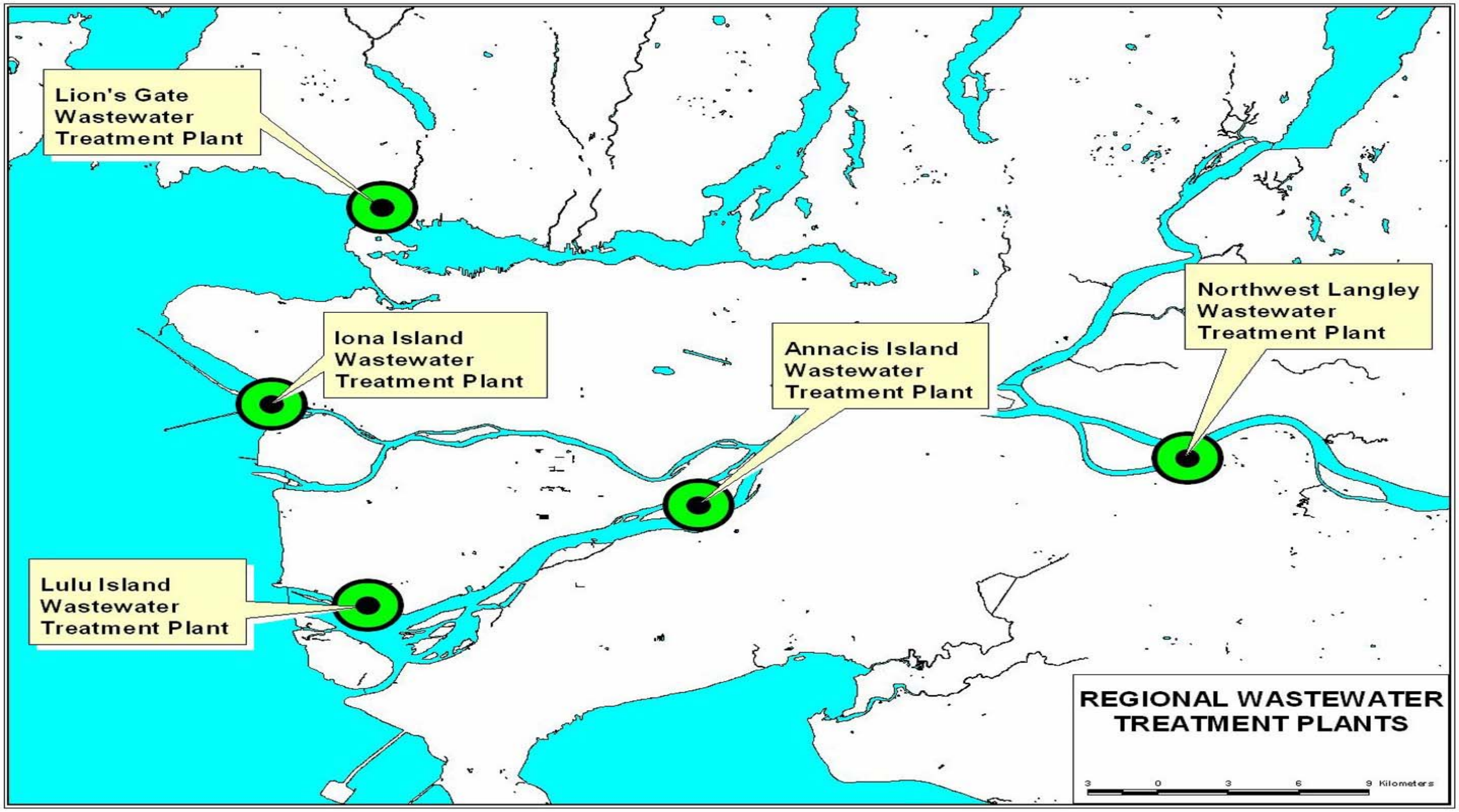
The Lions Gate WWTP is located on the North Shore, immediately adjacent to the Lions Gate Bridge, and serves the City of North Vancouver and Districts of West and North Vancouver. The discharge occurs through a single diffuser approximately 200 m offshore and at a depth of 20 m in First Narrows. The average discharge is approximately 100 MLD.

The Annacis Island WWTP is located on Annacis Island in the main arm of the Fraser River and serves the Cities of Burnaby, New Westminster, Port Moody, Port Coquitlam, Coquitlam, Surrey, Langley and White Rock, the Corporation of Delta, the Districts of Pitt Meadows and Maple Ridge, part of the Township of Langley, and parts of the Cities of Vancouver and Richmond. The discharge occurs through a diffuser system approximately 98 m offshore and at a depth of 9.1 m in the Annacis Channel of the Fraser River. The average discharge is 500 MLD.

The Lulu Island WWTP is located in south Richmond and serves the western part of the City of Richmond. The discharge occurs through a single diffuser approximately 120 m offshore and at a depth of 8.6 m in the Main Arm of the Fraser River. The average discharge is approximately 100 MLD.

The NW Langley WWTP is located in Langley Township near Barnston Island and serves the western portion of the Township of Langley. The discharge occurs through a single diffuser approximately 126 m offshore and at a depth of 7.2 m in the Main Stem of the Fraser River. The average discharge is approximately 10 MLD

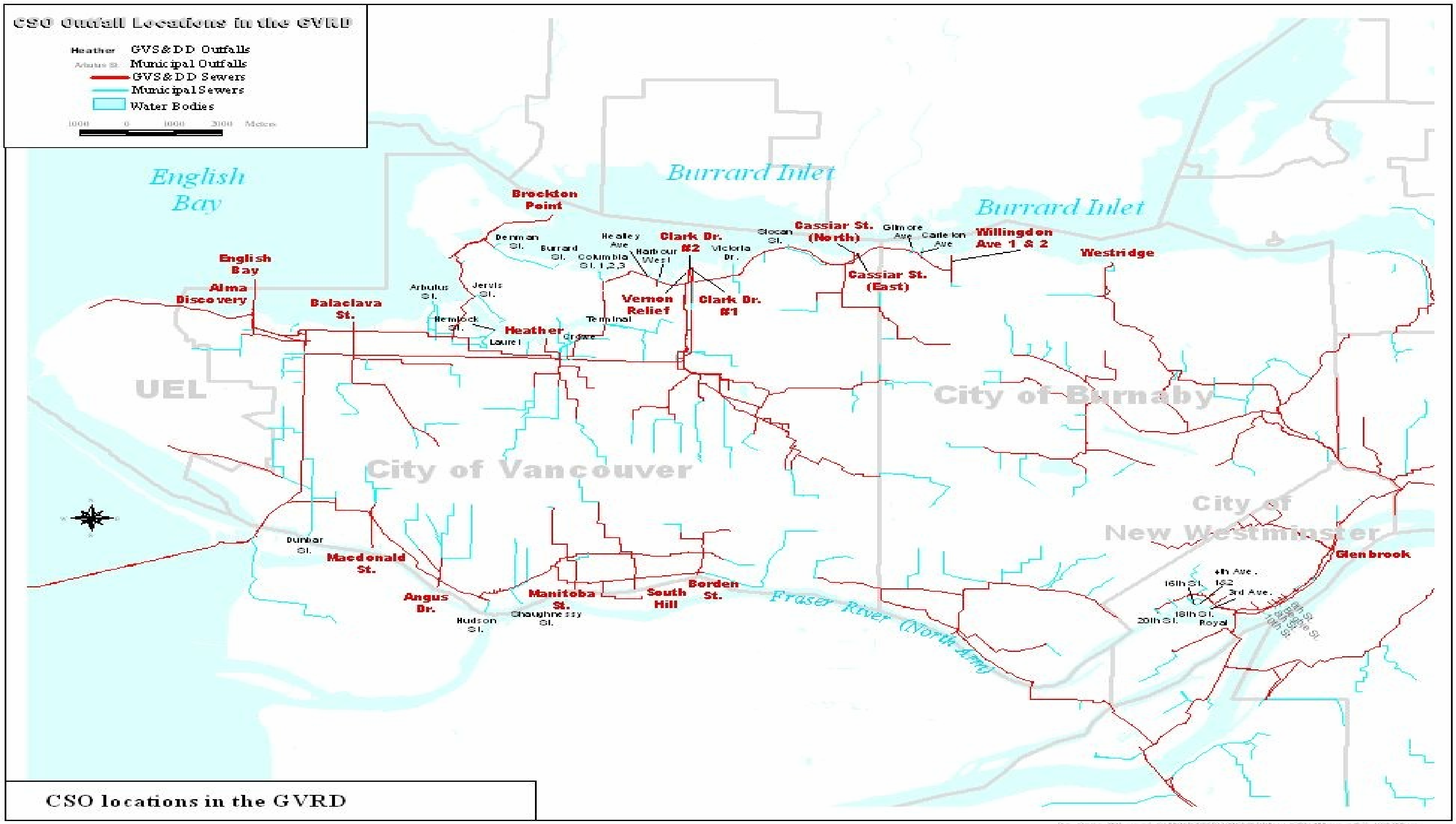
Figure 2. WWTP Locations



Both the Annacis Island and Iona Island sewerage systems include combined sewers that convey a mixture of sanitary wastewater and stormwater to the two WWTPs. During periods of heavy rainfall, the combined sewers fill up to capacity resulting in discharge of wastewater directly to the receiving environment via combined sewer overflows (CSOs). Within the GVRD, there are currently 49 CSOs at 42 locations (Figure 3). CSO reduction programs which include sewer separation and sewer system operational improvements are resulting in continuous CSO reduction in accordance with commitments under the LWMP.

The Lions Gate sewerage area is a separate system; however, some infiltration of ground and rainwater occurs at times. Infiltration and inflow control programs are also included in the LWMP commitments. The Lulu Island and NW Langley sewerage systems are relatively new separate systems. In separate sewerage areas, stormwater runoff is conveyed to streams, lakes, rivers and the marine environment by overland drainage systems and/or storm sewers.

Figure 3. CSO Locations in the GVRD



1.6 STRUCTURE OF THE DOCUMENT

The monitoring framework outlined in this document is founded upon the development of caution, warning and trigger indicators, which are indicative of wastewater or stormwater effects that can indicate adverse ecological changes.

The cautions, warnings and triggers process is applied to water column water, sediment, benthos and higher trophic levels. Each chapter of the document outlines an approach for eliciting a response to a given change in, or specified level of, environmental effects. The document is structured as follows:

- Chapter 1 – Introduction
- Chapter 2 – Water Column
- Chapter 3 – Sediment
- Chapter 4 – Benthos
- Chapter 5 – Higher Trophic Levels
- Chapter 6 – Summary and Conclusions

Technical Reports providing integral supportive information to the cautions, warnings and triggers process outlined in this document are provided in Appendices A through D. Appendix E consists of support material for Chapter 2. A summary of Environmental Monitoring Programs is provided in Appendices F through K.

1.6.1 Criteria and Integrative Technical Reviews

Several technical reviews have been undertaken in preparation this document and process (Appendices A to E). This information was used to identify and select appropriate indicators and provide the supporting information required to developing the cautions, warnings and trigger levels outlined herein.

1.6.2 GVRD Monitoring Programs

In accordance with commitments under GVRD's Liquid Waste Management Plan, the GVRD conducts extensive monitoring to evaluate potential environmental and human health effects of municipal liquid waste discharges and to provide key information respecting the cautions, warnings and triggers framework.

Environmental monitoring programs include the following components:

- Receiving environment monitoring programs for GVRD wastewater treatment plant outfalls (Appendix F);
- Ambient monitoring of the Lower Fraser River and southern portion of the Strait of Georgia (Appendix G);
- WWTP effluent monitoring (Appendix H);

- Combined and sanitary sewer overflows monitoring (Appendix I);
- Stormwater effects monitoring (Appendix J); and,
- Recreational water monitoring (Appendix K).

CHAPTER 2.

WATER COLUMN

2.1 INTRODUCTION

2.1.1 Overview

This chapter outlines the approach for establishing and assessing water column Cautions, Warnings and Triggers. The approach is based on comparing water quality values with either Provincial Water Quality Guidelines or site-specific Water Quality Objectives.

A table summarizing the water bodies and associated water column PWQG that apply to each GVRD WWTP and CSO is provided in Appendix E. A table summarizing the WQO that apply in the receiving environment of each GVRD WWTP and CSO is also provided in Appendix E. This table does not include the Iona Island WWTP because the receiving environment for this discharge does not have established WQO.

Although a water body may be classified as freshwater, marine or estuarine, some guidelines not normally associated with that type of water body may apply. For example, the stretch of the Fraser River downstream of the Trifurcation is considered estuarine; however, its uses include freshwater, estuarine and marine aquatic life. PWQG for these uses vary. To protect the most sensitive use when assessing Caution levels, monitoring results are compared with the most stringent guideline value.

2.1.2 Initial Dilution Zones (IDZ)

Provincial Water Quality Guidelines (PWQG) and site specific Water Quality Objectives (WQO) do not apply within the initial dilution zones (IDZs) of municipal effluent discharges. The IDZs for the different types of waterbodies in the GVRD are defined in Table 1.

Table 1. Definitions of Initial Dilution Zones

Fraser River (Stream or Estuary)	**Burrard Inlet and Strait of Georgia (Lake or Marine)**
• 100m upstream to 100 m downstream from point of discharge, from bed to surface • Maximum of 100m or 25% of the width of the river from either side of the outfall whichever is less	• 100m in all directions from point of discharge, from bed to surface; or, 25% of the width of the water body, whichever is less.

For discharges from an outfall diffuser, the radius may be measured from the first and last diffuser ports. Figures showing the IDZ for each GVRD wastewater treatment plant discharge are provided in Appendix E.

Between 1996 and 2002, dilution and dispersion studies were completed at the Annacis Island (Seaconsult and ABR, 1997), Lulu Island (Seaconsult, 1997), Iona Island (Seaconsult, 1999), Lions Gate (Seaconsult and EVS, 1999) and Northwest Langley (Seaconsult, 2002) WWTPs. These studies determined the effluent dispersion patterns in the receiving environment based on a model developed by Seaconsult Marine Research Limited for the GVRD. In addition, minimum instantaneous dilutions and 25 hour average dilutions of whole effluent at the initial dilution zone boundaries were determined based on the model, and confirmed by measuring effluent dilutions in the receiving environment using rhodamine dye. Table 2 provides a summary of the instantaneous and average dilutions at the IDZ boundaries for each GVRD WWTP.

Table 2. Receiving Environment Dilutions for GVRD WWTPs

	Lions Gate	**Iona Island**	**Annacis Island**	**Lulu Island**	**NW Langley**
Minimum Predicted Dilution	7:1 (dry weather) to 11:1 (wet weather)	102:1	7:1 (low flow) to 20:1 (freshet)	8:1 (low flow)	51:1 (low flow) to 1000:1 (freshet)
Average Predicted Dilution	250:1	150:1	40:1 (low flow) to 60:1 (freshet)	30:1 (low flow)	575:1 (low flow) to 3500:1 (freshet)

Dilution estimates have also been derived for all GVRD and municipal CSOs (Seaconsult, 2001). Dilution estimates have not been determined for stormwater discharges into the receiving environment.

2.2 METHODOLOGY FOR DETERMINING WATER COLUMN INDICATORS, CAUTIONS, WARNINGS AND TRIGGERS

The model described in Section 2.2.1 was developed to determine the substances (indicators) for which water column Cautions, Warnings and Triggers can be established and to determine the appropriate levels at which to set a Caution, Warning and/or Trigger. A number of outputs are provided by the model including:

- Estimated concentrations of substances at the IDZ boundary for discharges into the receiving environment;
- Concentrations of substances at the IDZ boundary relative to PWQG and WQO;
- Effluent contribution to the concentration at the IDZ boundary;
- Background contribution to the concentration at the IDZ boundary;
- Gaps in data required to estimate the IDZ boundary concentration; and,
- Identification of substances that have analytical detection limits that are not sensitive enough to compare the IDZ boundary concentrations with PWQG and WQO.

The model was run using the data outlined in Section 2.2.4 to determine substances that can be used as indicators at each GVRD WWTP and CSO and to identify the appropriate Cautions, Warnings and Triggers levels for water column PWQG and WQO. Although some background concentrations were obtained from monitoring conducted in years other than 2002, it was assumed that the data were representative of ambient conditions in 2002. In addition, the combined sewer overflow effluent concentrations provided in the 1998 CSO characterization study are assumed representative of 2002 levels.

2.2.1 IDZ Boundary Water Quality Evaluation Model

The applicable equation for the IDZ boundary water quality evaluation model is:

$$C_{IDZ} = C_{eff} / (DF + 1) + C_{bg} / (1 + 1/DF)$$

Where:
C_{IDZ} = Mixed plume concentration at the IDZ boundary (mg/L)
C_{eff} = Effluent quality (mg/L)
C_{bg} = Receiving environment background concentration (mg/L)
DF = Dilution factor [ratio of dilution water to effluent]

The first term in the model represents the liquid waste effluent contribution to the mixed plume concentration at the IDZ boundary. The second term represents the receiving environment background contribution to the mixed plume concentration at the IDZ boundary. The model, therefore, provides an opportunity to separate and evaluate the relative contributions of these components. This can be important in the following circumstances:

1. Background data are close to or above applicable receiving environment criteria.

In some cases, the IDZ boundary concentration may approach or exceed the applicable Caution, Warning and/or Trigger levels due to elevated background concentrations. At the same time the IDZ contribution from WWTP or CSO effluent may be minimal. Separating the respective contributions provides an opportunity to assess whether reductions in WWTP or CSO effluent concentrations would make a meaningful contribution to required contaminant reductions in the receiving environment.

2. Dealing with uncertainties associated with the available receiving environment background data.

Receiving environment data are often quite limited, or may be reported at less than detection limit concentrations or actual levels may be much lower than the detection limit. The use of limited data or detection limit data that are not representative could overstate the mixed plume concentration at the IDZ. This would reduce the allowable WWTP or CSO effluent concentration. Separating the respective contributions provides an opportunity to exercise judgement during interpretation of the results.

3. Receiving environment data may include contaminant contributions that are associated with particulate matter, for example, particulates associated with the river sediment load.

BC Water, Land and Air Protection reporting of receiving environment background data sometimes note that contaminant levels are associated with non-soluble particulate matter. It is also noted that the soluble bio-available fraction is of concern from an aquatic toxicity perspective. Where Caution, Warning and Trigger levels are approached using total concentrations, it would be worthwhile to consider the estimated soluble fraction. This applies to both the WWTP or CSO contribution and the receiving environment contribution.

In carrying out an evaluation to protect the receiving environment, the mixed plume concentration at the IDZ boundary is the dependent variable of interest. The evaluation model is properly focused on determining this variable (i.e. concentration at the IDZ boundary) as a function of the input parameters, and comparing with the applicable receiving environment criteria. The model lends itself well to evaluating options of maintaining the dependent variable within limits by, for example:

- Reducing WWTP or CSO influent loadings
- Improving WWTP contaminant removal capability
- Improving WWTP or CSO effluent dispersion characteristics
- Addressing sources that contribute to elevated receiving environment background levels

The model may be used to evaluate alternate scenarios, conditions or criteria on their effect on the mixed plume concentration at the IDZ. For example, the model may be used to:

- Assess the effect of alternative WWTP performance levels (i.e. contaminant removal)
- Assess the effect of peak influent loadings

- Assess alternative dilution scenarios related to plant or CSO flow, river flow and tide conditions
- Evaluate results against water quality criteria to protect designated water uses

2.2.2 Using the Model to Compare IDZ Boundary Levels with PWQG and WQO

Both maximum and average Water Quality Guidelines and Objectives have been established in BC. The model can be used to estimate both maximum and average concentrations at the IDZ for comparison with both types of PWQG and WQO.

For comparison with maximum PWQG and WQO, the maximum IDZ boundary concentrations are calculated using the model with the following input parameters:

> C_{IDZ} = Maximum mixed plume concentration at the IDZ boundary (mg/L)
> C_{eff} = Annual average effluent quality (mg/L)
> C_{bg} = Average receiving environment background concentration (mg/L)
> DF = Minimum instantaneous dilution factor at low or dry weather flow

C_{eff} is the calculated annual average effluent concentration of a substance and C_{bg} is the calculated average concentration of a substance at a given location in the ambient receiving environment. Use of the average effluent and background concentrations along with the minimum instantaneous dilution at low flow is assumed to represent most realistic conditions since maximum concentrations are unlikely to occur concurrently with minimum instantaneous low flow dilution.

For comparison with average PWQG and WQO, the average IDZ boundary concentrations are calculated using the model with the following input parameters:

> C_{IDZ} = Average mixed plume concentration at the IDZ boundary (mg/L)
> C_{eff} = Annual average effluent quality (mg/L)
> C_{bg} = Average receiving environment background concentration (mg/L)
> DF = Average dilution factor at low or dry weather flow

C_{eff} is the calculated annual average effluent concentration of a substance, C_{bg} is the calculated average concentration of a substance at a given location in the ambient receiving environment and DF is the 25 hr average dilution estimated by the C3 model developed by Seaconsult during the WWTP effluent dilution and dispersion studies. Although the average PWQG and WQO are based on a minimum of 5 samples within a 30 day period, it is assumed that these inputs best represent a 30 day average condition for comparison with the PWQG and WQO.

Since both instantaneous minimum and 25 hr average dilutions have been calculated for the WWTPs, the model can be used to estimate both maximum and average IDZ boundary concentrations for comparison with the maximum and average PWQG and WQO, respectively. However, only instantaneous minimum dilutions have been determined for the CSOs; therefore, only the maximum IDZ boundary concentration can be calculated and compared with maximum PWQG and WQO using the model.

2.2.3 Assumptions used in the Model

The assumptions used in the model are:

1) The estimated minimum instantaneous dilution at low flow or dry weather can be used to calculate maximum concentrations at the IDZ boundary for comparison with maximum PWQG and WQO.

2) The estimated average dilution at low flow or dry weather can be used to calculate average concentrations at the IDZ boundary for comparison with average PWQG and WQO.

3) For substances that are routinely monitored in the WWTP effluent, the annual average effluent concentration of a substance can be used to determine C_{eff} in the model.

4) For substances that are monitored during a WWTP effluent characterization study, the average of all samples analyzed during the study can be used to determine C_{eff} in the model.

5) The average background concentration at a specific location can be used for C_{bg} in the model.

6) Marine PWQG apply at the IDZ boundary of the Iona Island WWTP. Marine PWQG and WQO apply at the IDZ boundary of the Lions Gate WWTP and the Westridge, Willingdon, Cassiar, Clark Drive, Brockton, Heather, Balaclava, and English Bay/Alma Discovery CSOs.

7) Freshwater PWQG and WQO apply at the IDZ boundary of the Northwest Langley WWTP and the Glenbrook CSO.

8) Both marine and freshwater PWQG and WQO apply at the IDZ boundary of the Annacis Island and Lulu Island WWTPs and the Manitoba, Angus, MacDonald, South Hill and Borden CSOs.

2.2.4 Data Used in the Model

Existing monitoring data were used in the model to compare IDZ boundary concentrations with PWQG or WQO to provide a basis for identifying indicators and for establishing the Caution, Warning and Trigger levels at the IDZ boundary. It was assumed that existing monitoring programs could not be used at this time to establish these levels. However, when a review of a program is undertaken, the need to establish a Caution, Warning and/or Trigger level will be considered as part of the program redesign, if necessary.

The data include estimated dilution values at the IDZ boundary for each WWTP as outlined in Table 2; effluent and background concentrations of substances at all five GVRD WWTPs as outlined in Table 3; estimated instantaneous minimum dilution values at the IDZ boundary of each CSO (Seaconsult, 2001); estimated effluent characteristics for each CSO (Lee, 1998); background concentrations, where available, for each GVRD CSO as outlined in Table 4; and, available ambient monitoring data (Enkon, 2003a).

Table 3. WWTP Effluent and Background Monitoring Data Sources
(Continued page 26)

WWTP	Effluent Data	Background Data	Comments
Iona Island	2002 routine (GVRD, 2002) 1997 Effluent Characterization Study (Bertold & Stock, 1999)	All samples from the 1996 water column monitoring program (IRC and GVRD, 1997) that had less than 100 fecal coliforms/100ml.	Effluent is not disinfected.
Lions Gate	2002 routine (GVRD, 2002) 1997 Effluent Characterization Study (Bertold & Stock, 1999)	"Reference 1" site from the 2001 Reconnaissance Water Quality Sampling Study (Enkon, 2001a).	Effluent disinfected from May 1st to September 30th.
Annacis Island	2002 routine (GVRD, 2002) 1997 Effluent Characterization Study (Bertold & Stock, 1999)	Reference sites from the 2002 Annacis Island WWTP IDZ monitoring program (Enkon, 2003b), except iron (not analyzed) and fecal coliform (samples taken when WQO does not apply). Iron: Site 3 (Upstream of Sapperton Bar from the 2003 Fraser River Water Column Sampling Study (Enkon, 2003a). Fecal Coliforms: Jul 1 – Sept	Full secondary treatment began in 1999. Fecal Coliforms Effluent currently disinfected from May 1 to October 31. WQO is applicable from April 1 to October 31. Disinfection period to be April 1 to October 31 starting in 2004.

WWTP	Effluent Data	Background Data	Comments
		30 results from site 4 of the 2002 confirmation sampling program for the Fraser River Bacteriological Risk Assessment Study (Lewis & Bush, 2002).	
Lulu Island	2002 routine (GVRD, 2002)	Site 4 (Main Arm off Tilbury Island) for the 2003 Fraser River Water Column Monitoring Study (Enkon, 2003a) Fecal Coliforms: Jul 1 – Sept 30 results from site 7 of the 2002 confirmation sampling program for the Fraser River Bacteriological Risk Assessment Study (Lewis & Bush, 2002).	Full secondary treatment began in 1999. Fecal Coliforms Effluent currently disinfected from May 1 to September 30. WQO is applicable from April 1 to October 31. Disinfection period to be April 1 to October 31 starting in 2004.
NW Langley	2002 routine (GVRD, 2002)	Site 1 (Upstream end of MacMillan Island) for the 2003 Fraser River Water Column Monitoring Study (Enkon, 2003a) except fecal coliforms (samples taken when WQO does not apply). Fecal Coliforms: Jul 1 – Sept 30 results from site 2 of the 2002 confirmation sampling program for the Fraser River Bacteriological Risk Assessment Study (Lewis & Bush, 2002).	Effluent currently disinfected year-round. WQO is applicable from April 1 to October 31. Disinfection period to be April 1 to October 31 when new Operational Certificate is issued.

During the 1997 effluent characterization study, trace metals and selected organics were monitored in the effluents of the Iona Island, Lions Gate, Annacis Island and Lulu Island WWTPs. At that time, partial secondary treatment was in place at the Annacis Island WWTP and the effluent samples were taken immediately after the secondary treatment process. The Lulu Island WWTP was a primary plant at the time of the 1997 study; therefore, the data collected from the effluent at that time do not represent current conditions because the plant was converted to secondary treatment in 1999. The Northwest Langley WWTP was not included in the 1997 characterization study because the plant was not a GVRD WWTP at that time. Therefore, relevant trace metals and organics analysis results to calculate concentrations at the IDZ boundary of the Lulu Island and NW Langley WWTPs are not currently available.

Table 4. CSO Background Data Sources

CSO	Background Data
Glenbrook	Site 3 (Upstream of Sapperton Bar) for the 2003 Fraser River Water Column Monitoring Study (Enkon, 2003a)
South Hill, Manitoba, Angus, MacDonald, Borden	Site 6 (Near Boundary Road) for the 2003 Fraser River Water Column Monitoring Study (Enkon, 2003a)
English Bay/Alma Discovery, Balaclava	“Reference 1” site from the 2001 Reconnaissance Water Quality Sampling Study (Enkon, 2001a).
Brockton	No Data Available
Heather	No Data Available
Clark/Vernon	No Data Available
Cassiar	No Data Available
Willingdon	No Data Available
Westridge	No Data Available

Censored Data

Some monitoring results include censored data (data that are below the minimum detection limit of the laboratory test). A non-detectable value does not necessarily mean that a substance is not present, only that it is not at measurable levels. A number of approaches exist for handling censored data including the assumption that the result is equal to the detection limit, ½ of the detection limit, or zero (USEPA, 2000).

For this assessment, if less than 15% of the analysis results for a particular substance were non-detects, these values were then replaced by ½ of the detection limit for the purposes of calculating an average concentration. This commonly used method provides the best estimate of the true distribution and related statistical properties (Macdonald, R.H., 2003; USEPA, 2000).

If greater than 15% of the analytical results were non-detects, estimating the true distribution becomes increasingly uncertain and may lead to inaccurate statistical calculations. In this situation, replacing the non-detects by ½ of the detection limit may either overestimate or underestimate the true distribution. Therefore, for this assessment, if greater than or equal to 15% of the analysis results for a particular substance were non-detects, the values were replaced by the detection limit for the purposes of calculating an average concentration. Although this is a conservative approach, when more than 15% of the analysis results are non-detects, replacing the non-detects by the detection limit may considerably overestimate the true concentration. Therefore, calculated concentrations for these substances are italicized and preceded by a less-than symbol to highlight the uncertainty associated with the result.

Dependant Data

Some PWQG and WQO values for the Fraser River depend on ambient conditions. For example, the maximum instantaneous and 30-day average concentrations of ammonia vary with ambient pH and temperature. Other values also depend on pH, temperature, hardness and the concentration of chloride. The PWQG and WQO values used in this report are calculated using average ambient monitoring data for the Fraser River. For the Annacis Island WWTP, these data were obtained from the 2002 IDZ boundary monitoring study (Enkon, 2002). For the Lulu Island and NW Langley WWTPs, these data were obtained from the 2003 Fraser River water column sampling program (Enkon, 2003a).

2.3 INDICATORS FOR ASSESSING WATER COLUMN CAUTIONS, WARNINGS AND TRIGGERS

The inclusion of substances as indicators for establishing water column Cautions, Warnings and Triggers is based on model results using the data outlined in Section 2.2.4. The results are provided in Appendix E. Indicators are either full or partial.

2.3.1 Full Indicators

For the purposes of establishing water column Cautions, Warnings and Triggers for GVRD wastewater effluents, indicators are defined as substances that:

- Have an associated BC PWQG and WQO;
- Are monitored in GVRD wastewater effluents and the ambient (background) environment;
- Are expected to be found at measurable levels in GVRD wastewater effluents;
- Have background levels that are lower than established PWQG and WQO;
- Have an analytical detection limit that is lower than the PWQG and WQO; and,
- Do not have confounding factors that make it difficult to determine the contribution of the liquid waste discharge to the concentration at the IDZ boundary.

Substances that meet all requirements for use as full indicators at each WWTP are summarized in Table 5.

Table 5. Full Water Column Indicators for GVRD WWTPs

WWTP	Full Indicators
Iona Island	Arsenic, Cadmium, Copper, Lead, Mercury
Lions Gate	Fecal Coliforms (May 1 – Sept 30), Copper, Lead, Mercury, Zinc, Nickel
Annacis Island	Fecal Coliforms (Apr 1 – Oct 31), Suspended Solids, Ammonia, Copper, Lead, Manganese, Zinc, Total Aluminum, Arsenic, Barium, Boron, Cobalt, Iron, Molybdenum, Nickel, Selenium, Antimony, Beryllium, Lithium, Thallium, Vanadium
Lulu Island	Fecal Coliform (Apr 1 – Oct 31), Suspended Solids, Ammonia, Copper, Lead, Manganese, Zinc, Cobalt, Iron, Nickel, Silver,
NW Langley	Fecal Coliform (Apr 1 – Oct. 31), Suspended Solids, Ammonia, Arsenic, Copper, Manganese, Zinc, Cobalt, Iron, Lead, Nickel, Silver, Nitrate

Background data are available for 8 of the 14 GVRD CSOs locations. Therefore, full indicators can be established for the English Bay, Alma Discovery, Angus, Borden, South Hill, MacDonald, Glenbrook and Manitoba CSOs. Only partial indicators can be established for the remaining 6 CSO locations. The substances that meet all requirements for use as full indicators at each of the 8 CSOs are listed in Table 6.

Table 6. Full Water Column Indicators for GVRD CSOs

CSO	Indicators
English Bay/Alma Discovery, Balaclava	Ammonia, Cadmium, Copper, Lead, Mercury, Nickel, Zinc
Manitoba, Angus, Borden, South Hill, MacDonald, Glenbrook	Ammonia, Suspended Solids, Arsenic, Cadmium, Copper, Iron, Lead, Mercury, Nickel, Zinc

The substances that will be used as full indicators in the Fraser River ambient environment are Ammonia, Nitrate, Nitrite, Arsenic, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Nickel, Silver and Zinc.

2.3.2 Partial Indicators

Partial indicators are defined as those substances that are monitored in the effluent but have no background or ambient data or have analytical detection limits that are lower than either the maximum or average PWQG but not both. For substances without background data, the background concentration will be assumed zero until data are obtained.

The substances that will be used as partial indicators at each GVRD WWTP are listed in Table 7 with rationale.

Table 7. Partial Water Column Indicators for GVRD WWTPs
(Continued page 31-32)

WWTP	Substance(s)	Rationale for Use as a Partial Indicator
Iona Island	Total Aluminum, Barium, Boron, Iron, Manganese, Molybdenum, Nickel, Selenium, Ammonia, Nitrate, Nitrite, Phenols, Suspended Solids, Beryllium, Vanadium, Chlorobenzenes, PAHs	No background data or background analytical detection limits higher than guideline value.
	Silver	The background concentration analytical detection limit is greater than 60% of the average PWQG. Therefore, the IDZ concentration can only be compared to the maximum PWQG.
Lions Gate	Iron, Dissolved and total Aluminum, Arsenic, Barium, Boron, Molybdenum, Selenium, Silver, Ammonia, Phenols, Nitrate/Nitrite, Beryllium, Vanadium, Chlorobenzenes, PAHs	No background data
	Cadmium	The GVRD lab analytical detection limit for the routine effluent monitoring is greater than the marine PWQG. However, the lowest achievable detection limits used during the 1997 effluent characterization study are less than the marine PWQG. Therefore, the IDZ concentration can only be compared to the Marine PWQG during an effluent characterization study.
Annacis Island	Dissolved Aluminum, Mercury, Phenols, Nitrate/Nitrite, PAHs Organochlorine Pesticides, Chlorobenzenes	No background data
	Cadmium	The GVRD lab analytical detection limit for the routine effluent monitoring is greater than both the marine and freshwater PWQG. Although the lowest achievable detection limits were used during the 1997 effluent characterization study, the detection

WWTP	Substance(s)	Rationale for Use as a Partial Indicator
		limit is still greater than the freshwater PWQG. In addition, the analytical detection limit for the background samples is equal to the marine PWQG but greater than the freshwater PWQG. Therefore, the IDZ concentration can only be compared to the Marine PWQG during an effluent characterization study.
	Silver	The GVRD lab analytical detection limit for the routine effluent monitoring is greater than the freshwater PWQG. Although the lowest achievable detection limits were used during the 1997 effluent characterization study, the detection limit is still greater than the freshwater PWQG. Therefore, the IDZ concentration can only be compared to the Marine PWQG.
	Cyanide	No background data and the GVRD lab analytical detection limit for the routine effluent monitoring is greater than the marine PWQG.
Lulu Island	Total and dissolved Aluminum, Barium, Boron, Mercury, Molybdenum, Nitrate/Nitrite, Phenols, Sulphate	No background data
	Cadmium	The GVRD lab analytical detection limit for the routine effluent monitoring is greater than both the marine and freshwater PWQG. Although the lowest achievable detection limits were used during the 1997 effluent characterization study, the detection limit is still greater than the freshwater PWQG. In addition, the analytical detection limit for the background samples is equal to the marine PWQG but greater than the freshwater PWQG. Therefore, the IDZ concentration can only be compared to the Marine PWQG during an effluent characterization study.

WWTP	Substance(s)	Rationale for Use as a Partial Indicator
NW Langley	Total and dissolved Aluminum, Barium, Boron, Mercury, Molybdenum, Phenols, Sulphate	No background data

Background data are not available for 6 of the 14 GVRD CSO locations: Heather, Brockton, Clark, Cassiar, Willingdon and Westridge. Therefore, only partial indicators can be established for these CSO locations. In addition, some substances in the other nine CSOs do not have background data. The substances that will be used as partial indicators at each GVRD CSO are listed in Table 8 with rationale.

Table 8. Partial Water Column Indicators for GVRD CSOs

CSO	Substance(s)
Heather, Brockton, Cassiar, Clark, Willingdon, Westridge	Suspended Solids, Ammonia, Arsenic, Barium, Cadmium, Copper, Iron, Lead, Mercury, Nickel, Zinc, PAHs & Organics
English Bay/Alma Discovery, Balaclava	Suspended Solids, Arsenic, Barium, Iron, PAHs & Organics
Manitoba, Angus, Borden, South Hill, MacDonald, Glenbrook	Barium, Mercury, PAHs & Organics

2.3.3 Excluded Substances

Some substances that currently have an associated PWQG and/or WQO do not meet all the requirements for inclusion as an indicator in the establishment of water column Cautions, Warnings and Triggers at this time. These substances are Tributyl Tin, Phthalate Esters, Polychlorinated Biphenyls, Trivalent and Hexavalent Chromium, Chlorine Residual and Cadmium (NW Langley WWTP only).

Tributyl Tin

The pesticide tributyl tin (TBT) is listed on the First Priority Substance List under the Canadian Environmental Protection Act and has been regulated in Canada since 1989. It is used as a general lumber preservative and slimicide (a chemical toxic to bacteria and fungi). Since the regulatory goal in Canada is to virtually eliminate the use of TBT and since the current uses would likely not result in discharges into the GVRD wastewater system, it is not expected to be present at measurable levels in GVRD wastewater effluents.

Phthalate Esters

Phthalates are a family of chemical compounds that have been developed in the last century. Although consumers never use them alone, they are incorporated into products that consumers use every day. About 80 percent of all the phthalates manufactured today are used as plasticizers (i.e. they make plastics flexible without sacrificing strength or durability). The use of flexible plastics is ubiquitous in North America. Their uses range from construction to toy-making to medical care. The remaining 20% of phthalates are used for such things as keeping nail polish from chipping, making perfume linger longer or making tool handles strong and more resistant to breakage. Others help adhesives, caulking, paint pigments and many other materials perform their jobs better.

Due to the ubiquitous presence of phthalate esters, it is virtually impossible to conduct an environmental sampling program in the total absence of these substances. Sampling programs have shown that phthalate results are artificially high because they are also present at relatively high levels in trip blanks. Therefore, numerous confounding factors are present which brings into question the validity of the results and currently nullifies the ability to compare these results with established PWQG.

Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are mixtures of up to 209 individual chlorinated compounds (congeners). Many commercial PCB mixtures are known in North America by the trade name Aroclor. PCBs have been used as coolants and lubricants in transformers, capacitors and other electrical equipment because they do not burn easily and are good insulators. The manufacture of PCBs was stopped in Canada and the U.S. in 1977 because of evidence that they are persistent and bio-accumulate in the environment. Products made before 1977 that may contain PCBs include old fluorescent lighting fixtures, electrical devices containing PCB capacitors and old microscope and hydraulic oils.

During the 1980’s, an interim Canadian Water Quality Guideline was established for PCBs, and included a water column guideline value. Subsequently, the province of BC adopted the interim Canadian Water Quality Guideline, including the water column value, for PCBs. However, it was later determined that PCBs highly partition to solids and the water column guideline value for PCBs was withdrawn from the Canadian Water Quality Guidelines. Although, the BC Water Quality Guidelines currently include a water column guideline value, it is based on a Canadian Water Quality Guideline that has been withdrawn due to more current and accepted scientific knowledge of the fate of this substance in the environment.

Trivalent and Hexavalent Chromium

Chromium can exist in nine different oxidation states. Trivalent Chromium, Cr(III), and Hexavalent Chromium, Cr(IV) are two of the three most common oxidation states with Cr(III) being the most stable.

PWQG have been established for Trivalent and Hexavalent Chromium. However, analysis for Trivalent and Hexavalent Chromium requires additional sample handling and specific analytical techniques that significantly increase the cost of analysis. GVRD effluent and ambient samples are currently analyzed for total chromium in an unfiltered sample as part of the standard suite of metals. There is no standard for determining the relative ratio of Trivalent or Hexavalent chromium to total Chromium.

Chlorine Residual

Chlorine is currently used to disinfect the wastewater effluent at the Annacis Island, Lulu Island, Northwest Langley and Lions Gate WWTPs. Following chlorination, the effluent is dechlorinated using sulfur dioxide. Currently, disinfection occurs year-round at the Northwest Langley WWTP and between May 1st and September 30th at the Annacis Island, Lulu Island and Lions Gate plants. The effluent from the Iona Island WWTP is not disinfected. In 2004 and beyond, disinfection will occur between April 1 and October 31 at the Annacis Island, Lulu Island and Northwest Langley WWTPs. The disinfection period will not change at the Lions Gate WWTP.

There is no background/ambient chlorine residual data and the analytical detection limit for effluent is equal to or greater than the maximum and average marine and freshwater guideline values. In addition, the discharge of residual chlorine is regulated by the existing WTTP discharge permits and regulation will likely continue under the new Operational Certificates to be issued by the MWLAP under the GVRD LWMP.

Bacteriological Indicators (non water use period)

The main receiving water uses that are affected by bacteriological indicators such as fecal coliforms are drinking, recreation and irrigation of crops that are eaten raw. Within the GVRD, none of the surface water bodies are used as a source of drinking water. Although recreational use is extensive throughout the region, areas of primary-contact recreation are monitored weekly for fecal coliforms by the GVRD between May 1 and September 30, the primary use period. The results are forwarded to the local Health Authorities who compare them with the WQO to decide whether a beach area should be posted. In 2002, the GVRD completed a preliminary risk assessment for use of Fraser River Water for Irrigation (Lewis and Bush, 2002). This study showed that irrigation is unlikely to occur between November 1 and March 31.

Therefore, Fecal Coliforms will be used as an indicator in Burrard Inlet only between May 1 and September 30 (swimming season). Fecal Coliform will be used as an indicator in the Fraser River only between April 1 and October 31 (irrigation season).

Cadmium, Cyanide and Sulphide

Cadmium at the NW Langley WWTP, and Cyanide and Sulphide in the marine environment will be excluded for the reasons outlined in Table 9.

Table 9. Rationale for Water Column Excluded Substances

Substance	Rationale for Exclusion as an Indicator
Cadmium	The Northwest Langley WWTP discharges into freshwater. The GVRD lab analytical detection limit for the routine effluent monitoring is greater than the freshwater PWQG. Although the lowest achievable detection limits were used during the 1997 effluent characterization study, the detection limit is still greater than the freshwater PWQG
Cyanide, Sulphide	The GVRD lab analytical detection limit is greater than the marine WQG for Cyanide. As well, there is no background concentration data for Cyanide in Burrard Inlet and the Strait of Georgia.

2.4 WATER COLUMN CAUTIONS, WARNINGS AND TRIGGERS

Water column Cautions are proposed based on calculated indicator substance levels at the municipal liquid waste discharge IDZ boundary relative to PWQG and/or measured indicator substance levels in the ambient receiving environment relative to PWQG. Warnings are proposed based on calculated indicator substance levels at the municipal liquid waste discharge IDZ boundary relative to WQO. Triggers are proposed based on measured indicator substance levels at the municipal liquid waste discharge IDZ boundary relative to WQO.

The water column Cautions, Warnings and Triggers for IDZ boundary conditions were established based on the results of the model using the data outlined in Section 2.2.4. The results are provided in Appendix E. The water column Caution level for the ambient environment was established based on the results of the 2003 Fraser River Water Column Sampling Program (Enkon, 2003a).

2.4.1 Cautions

PWQG are designed to assess ambient receiving environment quality and not specific effects from discharges. Therefore, the numerical values associated with the PWQG will be used as a benchmark for assessing Caution levels.

Ambient monitoring programs have been established to assess water, sediment, fish and mammal tissue quality in the Fraser River and Georgia Strait. Water column monitoring is currently included in the Fraser River Ambient Monitoring Program, whereas, the ambient monitoring program for the Strait of Georgia is focused on sediment and tissue chemistry since the Strait is the sink for substances in both sediment and water. The GVRD Fraser River Ambient Monitoring Program was implemented in 2003. Table 10 shows a comparison of the 2003 water column chemistry results with the BC PWQG. As shown in Table 10, most of the substances are well below their associated PWQG.

The GVRD conducts routine WWTP effluent quality monitoring daily, weekly and monthly depending on the substance. Approximately once every five years a larger set of substances is also analyzed as part of a WWTP effluent characterization study. In 1998, a study was completed that classified all CSOs within the GVRD based on three land-use categories; heavy industrial, light industrial and residential. Typical CSO effluent concentrations for each land-use category were developed using data available at that time.

Therefore, attainment of Caution levels can be assessed either by comparing measured ambient constituent concentrations with relevant PWQG or by comparing calculated IDZ boundary concentrations of the indicator substances with relevant PWQG. Based on the ambient monitoring program results shown in Table 10 and the model results provided in Appendix E, the proposed Caution level is:

- Calculated constituent concentration outside the Initial Dilution Zone is greater than or equal to 60% of the relevant Provincial Water Quality Guideline value

The model described in Section 2.2.1 will be used to assess attainment of IDZ boundary Caution levels. As new background and/or effluent data are obtained, C_{eff} and C_{bg} in the model will be updated.

Table 10. Comparison of Fraser Ambient Water Column Concentrations with PWQG

Substance	Measurement Description	Units	Site 1 - MacMillan Island (freshwater)			Site 2 - Barnston Island (freshwater)			Site 3 - Upstream of Sapperton Bar (freshwater)			Site 4 - Tilbury Island (estuarine)		
			Results	**WQG**	**% of WQG**	**Results**	**WQG**	**% of WQG**	**Results**	**WQG**	**% of WQG**	**Results**	**WQG**	**% of WQG**
Hardness	30 d avg	mg/ L	52	n/a	n/a	51	n/a	n/a	44	n/a	n/a	65	n/a	n/a
pH (1)	max	pH units	7.60	6.5-8.5	ok	7.60	6.5-8.5	ok	7.66	6.5-8.5	ok	7.94	6.5-8.5	ok
Conductivity	max	mS/cm	0.155	700	0.02%	0.152	700	0.02%	0.148	700	0.02%	0.628	700	0.1%
Turbidity (2)	max	NTU	7			6			7			9		
Oxygen (3)	30 d avg	mg/L	12.9	11.0		12.8	11.0		12.5	11.0		12.6	11.0	
(dissolved)	min	mg/L	12.4	9.0		12.4	9.0		12.1	9.0		12.2	9.0	
Dissolved Solids (total)	max	mg/L	87	500	17%	78	500	16%	80	500	16%	444	500	89%
Suspended Solids (4)	30 d avg	mg/L	3.0			4.3			9.0			11.5		
(total)	max	mg/L	5.0			5.0			12.0			16.0		
Chloride (5)	max	mg/L	2.3	100	2.3%	2.3	100	2%	3.3	100	3%	198	100	198%
Ammonia - N	30 d avg	mg/L	0.02	2.0	1%	0.02	2.0	1%	0.02	2.0	1%	0.0	2.0	2%
	max	mg/L	0.02	11.9	0%	0.03	13.6	0%	0.0	10.3	0.2%	0.1	7.4	1%
Nitrate - N	30 d avg	mg/L	0.1	40.0	0%	0.2	40.0	0%	0.2	40.0	0.5%	0.2	40.0	0.5%
	max	mg/L	0.2	10.0	2%	0.2	10.0	2%	0.2	10.0	2%	0.2	10.0	2%
Nitrite - N	30 d avg	mg/L	0.003	0.0	8%	0.004	0.04	9%	0.0	0.04	9%	0.004	0.2	2%
	max	mg/L	0.004	0.1	3%	0.005	0.1	4%	0.0	0.1	4%	0.005	0.6	1%
Metals														
Arsenic	max	mg/L	0.0006	0.005	12%	0.0006	0.005	12%	0.0006	0.005	11%	0.0005	0.005	10%
Cadmium (6)	max	mg/L	0.00002	0.053	0.04%	0.00002	0.052	0.04%	0.00001	0.045	0.03%	0.00002	0.064	0.03%
Calcium (8)	max	mg/L	16	1000	2%	16	1000	2%	15	1000	1%	17	1000	2%
Chromium	max	mg/L	< 0.0002	0.001	< 20 %	< 0.0002	0.001	< 20 %	< 0.0002	0.001	< 20 %	< 0.0002	0.001	< 20 %
Cobalt	max	mg/L	0.00008	0.0009	9%	0.00010	0.0009	11%	0.00013	0.0009	14%	0.00014	0.0009	16%
Copper	30 d avg	mg/L	0.001	0.00004	1750%	0.001	0.00004	2200%	0.001	0.002	56%	0.001	0.002	54%
	max	mg/L	0.001	0.0069 (9)	13%	0.001	0.0068 (9)	15%	0.002	0.0061 (9)	25%	0.002	0.003	50%
Iron	max	mg/L	0.137	0.3	46%	0.154	0.3	51%	0.208	0.3	69%	0.191	0.3	64%
Lead	30 d avg	mg/L	0.0001	0.005	2%	0.0001	0.005	2%	0.0002	0.004	4%	0.0001	0.002	7%
	max	mg/L	0.0001	0.036	0.3%	0.0001	0.034	0.4%	0.0003	0.028	1%	0.0002	0.048	0.4%
Manganese	30 d avg	mg/L	0.01	2.9	0.4%	0.01	2.8	0.5%	0.014	2.5	0.6%	0.014	3.5	0.4%
	max	mg/L	0.02	0.2	9%	0.02	0.2	8%	0.017	0.2	8%	0.018	0.1	18%
Nickel	30 d avg	mg/L	< 0.0005	n/a	n/a	< 0.0005	n/a	n/a	< 0.0007	n/a	n/a	< 0.0006	0.0083	7%
	max	mg/L	0.001	0.025	2%	0.001	0.025	2%	0.001	0.025	5%	0.001	0.025	3%
Silver	30 d avg	mg/L	< 0.00001	0.00005	20%	< 0.00001	0.00005	20%	< 0.00001	0.00005	20%	< 0.00001	0.00005	20%
	max	mg/L	< 0.00001	0.0001	< 10%	< 0.00001	0.0001	< 10%	< 0.00001	0.0001	< 10%	< 0.00001	0.0001	< 10%
Zinc	30 d avg	mg/L	0.005	0.0075	63%	0.001	0.0075	19%	0.003	0.0075	38%	0.002	0.0075	22%
	max	mg/L	0.020	0.033	59%	0.003	0.033	8%	0.008	0.033	23%	0.003	0.01	27%

(1) % of Guideline not calculated for pH. pH results meet guideline in all cases.
(2) Turbidy WQG based on increase over background.
(3) % of WQG not calculated because criteria based on minimum concentration.
(4) Suspended solids WQG based on increase over background.
(5) Chloride guideline set to protect irrigation.
(6) Guideline values calculated using hardness results.
(7) Guideline for marine aquatic life. No hardness measurements; can't calculate guideline for freshwater aquatic life.
(8) Calcium guideline set to protect livestock. Likely not a use at Ewen Slough and McDonald Slough.
(9) Freshwater guideline values calculated using hardness results

Table 10. continued

Substance	Measurement Description	Units	Site 5 - Near Ewen Slough (estuarine)			Site 6 - Boundary (estuarine)			Site 7 - Near McDonald Slough (estuarine)		
			Results	WQG	% of WQG	Results	WQG	% of WQG	Results	WQG	% of WQG
Hardness	30 d avg	mg/ L		n/a	n/a	48	n/a	n/a	-	n/a	n/a
pH (1)	max	pH units	7.56	6.5-8.5	ok	7.84	6.5-8.5	ok	7.55	6.5-8.5	ok
Conductivity	max	mS/cm	17.6	700	2.51%	1.54	700	0.22%	15.1	700	2.16%
Turbidity (2)	max	NTU	15			15			14		
Oxygen (3)	30 d avg	mg/L	12.0	11.0		12.5	11.0		11.8	11.0	
(dissolved)	min	mg/L	11.9	9.0		12.1	9.0		11.5	9.0	
Dissolved Solids (total)	max	mg/L	9860	500	1972%	718	500	144%	8530	500	1706%
Suspended Solids (4)	30 d avg	mg/L	17.4			9.4			20.8		
(total)	max	mg/L	31.0			12.0			28.0		
Chloride (5)	max	mg/L	5590	100	5590%	333	100	333%	4990	100	4990%
Ammonia - N	30 d avg	mg/L	0.1	1.9	7%	0.1	2.0	3%	0.1	2.0	4%
	max	mg/L	0.1	18.3	1%	0.1	16.9	1%	0.1	18.3	0.4%
Nitrate - N	30 d avg	mg/L	0.3	40.0	1%	0.2	40.0	0%	0.2	40.0	1%
	max	mg/L	0.3	10.0	3%	0.2	10.0	2%	0.3	10.0	3%
Nitrite - N	30 d avg	mg/L	0.01	0.2	3%	0.003	0.2	2%	0.005	0.2	3%
	max	mg/L	0.01	0.6	1%	0.004	0.6	1%	0.006	0.6	1%
Metals											
Arsenic	max	mg/L	0.0005	0.005	10%	0.0005	0.005	10%	0.0005	0.005	10%
Cadmium (6)	max	mg/L	<0.0001	0.0001 (7)	< 100 %	0.00028	0.050	0.56%	<0.0001	0.0001 (7)	< 100 %
Calcium (8)	max	mg/L		1000	n/a	14.2	1000	1%		1000	n/a
Chromium	max	mg/L	0.0006	0.001	60%	< 0.0005	0.001	< 50%	0.0007	0.001	70%
Cobalt	max	mg/L	0.0003	0.0009	33%	0.00020	0.0009	22%	0.0005	0.00090	56%
Copper	30 d avg	mg/L	0.002	0.002	75%	0.001	0.002	69%	0.002	0.002	107%
	max	mg/L	0.002	0.003	63%	0.002	0.003	50%	0.003	0.003	113%
Iron	max	mg/L	0.350	0.3	117%	0.3	0.3	92%	0.750	0.3	250%
Lead	30 d avg	mg/L	0.0003	0.002	15%	0.0003	0.002	17%	0.0005	0.002	24%
	max	mg/L	0.001	0.140	0.4%	0.001	0.032	2%	0.0007	0.1	1%
Manganese	30 d avg	mg/L	0.020	n/a	n/a	0.017	2.7	0.6%	0.02	n/a	n/a
	max	mg/L	0.035	0.1	35%	0.021	0.1	21%	0.03	0.1	30%
Nickel	30 d avg	mg/L	0.001	0.0083	15%	0.001	0.025	3%	0.001	0.0083	17%
	max	mg/L	0.002	0.075	2%	0.001	0.025	4%	0.002	0.075	3%
Silver	30 d avg	mg/L	< 0.001	0.0015	< 67%	< 0.0002	0.00005	20%	<0.001	0.0015	< 67%
	max	mg/L	< 0.001	0.003	< 33%	<0.001	0.0001	< 10%	<0.001	0.003	< 33%
Zinc	30 d avg	mg/L	0.004	n/a	n/a	< 0.0028	0.0075	< 37%	0.005	n/a	n/a
	max	mg/L	0.010	0.01	100%	0.0	0.01	58%	0.007	0.01	70%

(1) % of Guideline not calculated for pH. pH results meet guideline in all cases.
(2) Turbidy WQG based on increase over background.
(3) % of WQG not calculated because criteria based on minimum concentration.
(4) Suspended solids WQG based on increase over background.
(5) Chloride guideline set to protect irrigation.
(6) Guideline values calculated using hardness results.
(7) Guideline for marine aquatic life. No hardness measurements; can't calculate guideline for freshwater aquatic life.
(8) Calcium guideline set to protect livestock. Likely not a use at Ewen Slough and McDonald Slough.
(9) Freshwater guideline values calculated using hardness results

Response to Caution Levels

If a Caution level were met or exceeded, the GVRD may:

- Determine confounding effects (natural or anthropogenic);
- Determine degree to which GVRD discharges contribute to the excursion, if any;
- Determine direction and degree of trends;
- Increase monitoring to assess seasonal and/or long-term trends;
- Verify excursion with Caution level by monitoring at the IDZ boundary; and,
- Assess if the excursion is causing effects in benthic community structure.

Frequency of Assessment for Caution Levels

Attainment of Caution levels will be assessed as shown in Table 11.

Table 11. Frequency of Assessment for Water Column Caution Levels

Component	**Caution Level Assessment Frequency**
Fraser River Ambient	During the annual water column sampling program under the Fraser River Ambient Monitoring Program.
Iona Island WWTP	Annually for indicators that are sampled in the effluent at least once per month.
All WWTPs	During the WWTP effluent characterization studies for indicators that do not have WQO.
CSOs	During investigative studies such as characterizations studies or fate and effects studies for indicators that do not have WQO.WQO
Sewerage Systems	When a proposed change in source loadings of an indicator substance or number of indicator substances occurs, the model will be used to predict the change in calculated IDZ boundary concentration and whether the change will result in an exceedance of a Caution level.WQO

2.4.2 Warnings

Water Quality Objectives are designed to assess local receiving environment quality for a specific water body. Therefore, numerical values associated with established WQO will be used as benchmarks for assessing Warning and Trigger levels.

Water Quality Objectives have been established for the Fraser River and Burrard Inlet. Since there are no established WQO in the receiving environment of the Iona Island WWTP discharge, Warnings and Triggers based on a comparison with WQO cannot be established for the Iona Island WWTP. However, Warnings are proposed for the Annacis Island, Lulu Island, Northwest Langley and Lions Gate WWTPs and all GVRD CSOs based on a comparison of the calculated IDZ boundary concentrations with the established WQO.

Based on the model results provided in Appendix E, the proposed Warning level based on comparing calculated IDZ boundary concentrations with WQO is:

Calculated constituent concentration at the Initial Dilution Zone boundary is greater than or equal to 60% of the relevant Water Quality Objective value

The model described in Section 2.2.1 will be used to assess attainment of IDZ boundary Warning levels. As new background and/or effluent data are obtained, C_{eff} and C_{bg} in the model will be updated.

Response to Warning Levels

If a Warning level were met or exceeded, the GVRD may:

- Determine confounding effects (natural or anthropogenic);
- Determine degree in which GVRD discharges contribute to the excursion;
- Verify excursion with Warning level by monitoring at the IDZ boundary;
- Increase monitoring to assess seasonal and/or long-term trends and determine direction and degree of trends to predict if/when the indicator substance will exceed the Trigger level and WQO; and,
- Assess if the excursion is causing effects in benthic community structure.

Frequency of Assessment of Warning Levels

Attainment of Warning levels will be assessed as shown in Table 12.

Table 12. Water Column Warning Level Assessment Frequency

Component	Warning Level Assessment Frequency
Annacis Island, Lulu Island, NW Langley and Lions Gate WWTPs	Annually for indicators that are sampled at least once per month and during the WWTP effluent characterization studies
CSOs	During investigative studies such as characterizations studies or fate and effects studies.
Sewerage Systems	When a proposed change in source loadings of an indicator substance or number of indicator substances occurs, the model will be used to predict the change in calculated IDZ boundary concentration and whether the change will result in an exceedance of a Warning level.

2.4.3 Triggers

Water Quality Objectives have been established for the Fraser River and Burrard Inlet. Since there are no established WQO in the receiving environment of the Iona Island WWTP discharge, Warnings and Triggers based on a comparison with WQO cannot be established for the Iona Island WWTP. However, Triggers are proposed for the Annacis Island, Lulu Island, Northwest Langley and Lions Gate WWTPs and all GVRD CSOs based on a comparison of measured IDZ boundary concentrations with established WQO.

Based on the results of the IDZ boundary monitoring programs conducted at the Lions Gate WWTP (Enkon, 2001a) and the Annacis Island WWTP (Enkon, 2002), the proposed Trigger level based on comparing measured IDZ boundary concentrations with WQO is:

Measured constituent concentration at the Initial Dilution Zone boundary is greater than or equal to 80% of the relevant Water Quality Objective value

Response to Trigger Levels

If a Trigger level were met or exceeded, the GVRD may:

- Determine confounding effects (natural or anthropogenic);
- Determine degree in which GVRD discharges contribute to the excursion;
- Determine direction and degree of trends to predict if/when the indicator substance will exceed the WQO;
- Increase monitoring to assess seasonal and/or long-term trends; and/or,
- Follow the trigger mechanism outlined in Figure 3 of the LWMP:
    - Conduct a risk assessment, which includes whether the excursion is causing effects in the biological community, in consultation with the EMC;
    - Develop options for mitigation, if required, in consultation with the EMC;

- o Present the risk assessment and EMC recommended mitigation option(s) to the GVRD;
- o Present the risk assessment and EMC recommended mitigation option(s) to the MWLAP; and,
- o Implement mitigation measures that are accepted by the MWLAP.

Frequency of Assessment of Trigger Levels

Attainment of Trigger levels will be assessed as illustrated in Table 13.

Table 13. Water Column Trigger Level Assessment Frequency

Component	Trigger Level Assessment Frequency
Annacis Island WWTP	During the annual water column IDZ boundary sampling program under the Annacis Island, Lulu Island and Northwest Langely Receiving Environment Monitoring Program (McCallum, Hodgins, Burd, and Hewitt, 2003)
Lions Gate	During the water column IDZ boundary sampling program (currently conducted once every five years).
All WWTPs	If Caution or Warning levels indicate a rise in WWTP effluent concentration.
CSOs	During investigative studies such as characterizations studies or fate and effects studies.

2.5 CURRENT EXCURSIONS

Based on the model results provided in Appendix E, some indicator substances currently exceed Caution and/or Warning levels.

2.5.1 Lions Gate WWTP

Fecal Coliforms

As shown in Appendix E, the calculated fecal coliform concentration at the Lions Gate IDZ boundary in 2002 was 239% of the WQO, and the effluent portion alone was 230% of the WQO. In 2002, the type of disinfectant was changed from chlorine gas to liquid hypochlorite. In addition, an automated system was implemented to adjust the chlorine dose based on plant flow and chlorine residual levels prior to de-chlorination. The system change has resulted in some startup adjustment issues that led to short term high fecal coliform concentrations in the effluent. These high individual readings can significantly affect the geometric mean results.

Options for improving mixing in the chlorine contact chamber are currently being reviewed with the intent of maximizing the disinfection efficiency and reducing the risk of individual high fecal coliform levels in the effluent. These measures should ensure that the WQO for fecal coliforms are met at the Lions Gate WWTP IDZ boundary.

Weekly monitoring is conducted throughout the summer at the Ambleside and Dundarave beaches, which are in the area of the Lions Gate WWTP effluent plume. Monitoring results from 1999 to 2003, provided in Appendix H, show that the fecal coliform WQO has never been exceeded at these beaches during the past five years.

Ammonia

Based on the model results shown in Appendix E, the Ammonia concentration at the Lions Gate WWTP IDZ boundary would exceed the Caution level of 0.6WQG. The model indicates that the Lions Gate effluent would account for 104% of the maximum PWQG but only 8% of the average PWQG. There are no data on background ammonia for the Lions Gate WWTP.

When the LWMP was approved by the Minister of Water, Land and Air Protection, she included a requirement to evaluate non-ammonia related toxicity. Although, the Minister does not require a plan to address ammonia related toxicity at the Lions Gate WWTP, the GVRD did undertake a study (Associated, 2001) to identify options for reducing ammonia peaks in the effluent. Liquid from the solids drying process (Centrate) contains concentrated levels of ammonia and is returned to the headworks of the Lions Gate WWTP. Historically, the Centrate was constantly returned to the headworks and blended with the influent to the WWTP. Based on the study recommendations, the GVRD has implemented storage of Centrate between 8:00 a.m. and 12:00 noon when peak influent ammonia levels occur.

Cadmium

Based on the model results shown in Appendix E, the Cadmium concentration at the Lions Gate WWTP IDZ boundary would exceed the Caution level of 0.6PWQG. However, the background concentration of Cadmium accounts for 70% of the maximum PWQG whereas the Lions Gate WWTP effluent only accounts for 38% of the PWQG.

2.5.2 Annacis Island WWTP

Ammonia

Based on the model results shown in Appendix E, the Ammonia concentration at the Annacis Island WWTP IDZ boundary is at 60% of the maximum WQO and 63% of the average WQO, which exceeds the Warning level of 0.6WQO. The model indicates that the Annacis Island WWTP effluent would account for 59% and the background only 0.6% of the maximum PWQG, and that the effluent would account for 60% and the background only 3% of the average PWQG.

In 2001, a study was conducted on the fate and effects of ammonia in the Fraser River (Enkon, 2001b). The study concluded that “measured ammonia levels in the Fraser River do not pose a toxic risk.”

Cobalt

Based on the model results shown in Appendix E, the Cobalt concentration at the Annacis Island WWTP IDZ boundary is at 87% of the maximum PWQG, which exceeds the Caution level of 0.6PWQG for freshwater (there is no marine criteria). However, the background concentration of Cobalt accounts for 90% of the maximum PWQG whereas the Annacis Island WWTP effluent only accounts for 8% - <14% of the PWQG.

The 2003 ambient monitoring program results show that Cobalt increases in the river as it moves from Kanaka Creek to the mouths. Therefore, it is recommended that a study be initiated to identify sources and relative loadings of cobalt into the river.

Iron

Based on the model results shown in Appendix E, the Iron concentration at the Annacis Island WWTP IDZ boundary is at 75% of the maximum PWQG, which exceeds the Caution level of 0.6PWQG. The background concentration of Iron accounts for 52% of the maximum PWQG and the Annacis Island WWTP effluent accounts for 29%.

Based on model results, the GVRD has initiated a response in accordance with the Caution responses outlined in this report.

2.5.3 Lulu Island WWTP

Chloride

Based on the model results shown in Appendix E, the Chloride concentration at the Lulu Island WWTP IDZ boundary is 66% of the maximum freshwater PWQG, which exceeds the Caution level of 0.6 PWQG. However, the background concentrations of Chloride account for 60% of the PWQG whereas the Lulu Island WWTP effluent only accounts for 10%. The receiving environment at the Lulu Island WWTP discharge is subject to naturally high chloride levels due to saltwater incursion during flood tides.

The 2003 ambient monitoring program results show that Chloride increases significantly in the river as it moves from Kanaka Creek to the mouths. This would indicate that natural influences due to incursion of marine water up the river affects the chloride concentration in the river.

Silver

Although the analytical detection limit for silver is greater than the freshwater PWQG, detectable levels of silver were found in the Lulu Island WWTP effluent in 2002. Based on the model results shown in Appendix E, silver concentration at the Lulu Island WWTP IDZ boundary <157% of the maximum freshwater PWQG and <105% of the average freshwater PWQG, which exceeds the Caution level of 0.6WQO for freshwater. However, the levels are far below the

PWQG for marine water. The model indicates that the Lulu Island WWTP effluent alone would account for 86% of the average WQO and 148% of the maximum criteria for freshwater but only 3% and 5% of the average and maximum marine PWQG, respectively.

The GVRD has initiated a response based on the model results and in accordance with the Caution responses outlined in this report.

2.5.4 CSO Fecal Coliforms

Fecal Coliforms are indicators of bacterial contamination originating from the intestines of warm blooded animals. Raw wastewater, which is one component of wastewater, contains millions of fecal coliforms. Therefore, when wastewater discharges into the receiving environment via combined sewer overflows, a relatively high concentration of fecal coliforms is also discharged. However, these coliforms rapidly die off when discharged into the environment due to a number of factors, including predation and UV irradiation from natural sunlight.

The main receiving water uses that are affected by fecal coliforms are drinking, recreation and irrigation of crops that are eaten raw. Within the GVRD, none of the surface water bodies into which CSOs discharge is used as a source of drinking water. Although recreational use is extensive throughout the region, areas of primary-contact recreation are monitored weekly by the GVRD between May 1 and September 30, the primary use period. The results are forwarded to the local Health Authorities who compare them with the WQO to decide on whether a beach area should be posted. In 2002, the GVRD completed a preliminary risk assessment for use of Fraser River Water for Irrigation. This study showed that irrigation is unlikely to occur during wet weather periods when CSOs occur.

The GVRD and its member municipalities have committed, through the LWMP, to continuous improvements in the sewerage system and to the reduction and eventual elimination of CSOs. Therefore, a risk assessment has already been completed and a long-term plan is in place to continuously reduce and eventually eliminate CSOs into the receiving environment.

2.5.5 Copper (all)

Background copper levels have been analyzed in Burrard Inlet, Georgia Strait and the Fraser River. The results have shown that background levels in all these water bodies are elevated. Geochemistry investigations have shown that soils and rock in BC contain naturally high levels of copper. Low pH water is also prevalent throughout BC and readily leaches copper from the soils and rock. The copper is then transported into surface water bodies via direct contact with surface water bodies, groundwater or overland drainage.

In response to LWMP Commitment C24, the GVRD has concluded that the major source of copper in the wastewater system is from leaching of copper in the potable water distribution system due to naturally low pH of the water supply. Significant reductions in copper loadings will result from the implementation of pH adjustment as part of the GVRD’s comprehensive Drinking Water Treatment Program. The pH adjustment is currently taking place at the Seymour and Coquitlam water sources and will be added at the Capillano source as part of the half billion-dollar Seymour/Capillano filtration project. Following completion of the filtration plant in 2007, the pH of the water throughout the distribution system will be consistently maintained at pH 7.5, thereby reducing the aggressiveness of the water supply and copper loadings into the wastewater system.

CHAPTER 3.

SEDIMENT

3.1 INTRODUCTION

3.1.1 Criteria

Two main types of Criteria exist: Water Quality Objectives (WQO) and Provincial Water Quality Guidelines (PWQG).

Water Quality Objectives (WQO) or site-specific water quality guidelines are a refined set of criteria based on, and senior to, the province-wide guidelines. These are adapted with the intention of protecting the most sensitive water use at a specific location, considering local circumstances. As mentioned previously, WQO have their basis in the PWQG but include the site characteristics that may influence, positively or negatively, the toxic action of the substance of concern (e.g. naturally high “background concentrations” of certain substances). The Ministry of Water, Land and Air Protection (MWLAP) therefore recognizes that site-specific factors may require modification of the *Approved* or *Working* guidelines, and has published a means of accomplishing this in the 1997 publication: *Methods for Deriving Site-Specific Water Quality Objectives in British Columbia and Yukon*.

The PWQG are separated into two components: Approved Water Quality Guidelines (AWQG) and Working Water Quality Guidelines (WWQG). In general, PWQG are developed for the assessment of water quality data and the preparation of site-specific WQO. The intention is to provide initial benchmarks for the assessment of water quality and the setting of water quality objectives. In general, water quality problems are non-existent for the substance in question if the substance concentration is lower than the guideline(s). However, if the substance concentration exceeds its guideline(s), an assessment of the water quality and the implications or effects may be required.

AWQG are described and listed in the document: “*British Columbia Approved Water Quality Guidelines (criteria), 1998 edition. Updated August 24, 2001*”. Tables 2 through 43 in this document, list guidelines that have been developed by the Ministry of Environment, Lands and Parks (now Ministry of Water, Land and Air Protection, MWLAP). These have been approved by the Province and are used for the assessment of water quality in BC. Approved guidelines are given to protect six major water uses: Drinking Water, Aquatic Life (freshwater and marine), Wildlife, Recreation and Aesthetics, Agriculture (Irrigation and Livestock Watering) and Industrial (e.g., Food Processing Industry).

Table 1 of this same document is unique; it lists guidelines for drinking water (at the point of consumption) and recreational waters. These guidelines, designed to protect human health, are the responsibility of Health Canada. The list of substances considered by Health Canada is broader than that considered by the Province (Tables 2 through 43) and reflects a Canadian perspective. Drinking water guidelines as stated in Tables 2 through 43 are, in some cases, for raw waters before treatment and should not be confused with those in Table 1.

Approved Water Quality Guidelines apply province-wide, and are safe levels of substances for the protection of a given water use including drinking water, aquatic life, recreation and agricultural uses. In aquatic environments, water quality incorporates the physical, chemical and biological quality of the water, sediment and biota. These guidelines are continually developed by the Province, substance by substance on a priority basis, beginning with those more urgently needed for water quality assessments and objectives.

The Working Guidelines Compendium brings together Guidelines that have not yet been approved by the Province and are therefore termed “Working Guidelines”. These Guidelines were obtained from various Canadian (primarily the Canadian Council of the Ministers of the Environment or CCME) and other North American jurisdictions. The working guidelines provide provisional benchmarks for substances, which have not yet been fully assessed and formally endorsed by the Ministry. They are being reviewed by the Ministry on a priority basis for their formal approval and use in British Columbia.

In the BC documents, the terms ‘Guidelines’ and ‘Criteria’ are used interchangeably. From the introduction to the Working Compendium:

“The terms ***guidelines*** and *criteria* are synonymous; however, care must be exercised when numbers from BC and CCME are compared. In some instances, BC guidelines for a substance may be specified as two values: one to protect aquatic life from short-term, lethal effects (i.e., the maximum value or the acute criterion) and the other to protect it from long-term, sub-lethal effects (the 30-day average value or the chronic criterion). On the other hand, a CCME water quality guideline is always specified as a single maximum value to protect aquatic life from all adverse effects. CCME guidelines and BC chronic guidelines are generally similar in value”.

The conventional use of Criteria and Guidelines as synonyms will be followed in this document; however, in each case, the origin of the guideline or criterion will be stated (CCME, WWQG or AWQG).

3.1.2 Guidelines and Objectives for Sediment

Where WQO apply for the area of concern, values for substance concentrations in sediment are included, without exception.

However, this is not universally the case for Guidelines. The AWQG are predominantly associated with water column values, with only three minor exceptions: PAH, PCB and particulate matter, where the latter are values for Maximum Induced Suspended Sediments, and therefore not strictly a sediment, but rather a water column, criterion (see Tables 14 and 15).

Table 14. Summary of Aquatic Life and Sediment Criteria for Polycyclic Aromatic Hydrocarbons (PAH)

PAH	Fresh Water (chronic)	Fresh Water (phototoxic)	Marine Water	Sediments (Fresh Water)	Sediments (Marine)
Naphthalene	1 µg/L	NR	1 µg/L	0.01 µg/g	0.01 µg/g
Methylated naphthalene	NR	NR	1 µg/L	NR	NR
Acenaphthene	6 µg/L	NR	6 µg/L	0.15 µg/g	0.15 µg/g
Fluorene	12 µg/L	NR	12 µg/L	0.2 µg/g	0.2 µg/g
Anthracene	4 µg/L	0.1 µg/L	NR	0.6 µg/g	NR
Phenanthrene	0.3 µg/L	NR	NR	0.04 µg/g	NR
Acridene	3 µg/L	0.05 µg/L	NR	1 µg/g	NR
Fluoranthene	4 µg/L	0.2 µg/L	NR	2 µg/g	NR
Pyrene	NR	0.02 µg/L	NR	NR	NR
Chrysene	NR	NR	0.1 µg/L	NR	0.2 µg/g
Benz[a] anthracene	0.1 µg/L	0.1 µg/L	NR	0.2 µg/g	NR
Benzo[a]pyrene	0.01 µg/L	NR	0.01 µg/L	0.06 µg/g	0.06 µg/g

Table 15. Summary of Criteria for Polychlorinated Biphenyls (PCBs)

Water Use	PCBs	Recommended Maximum Concentration
Drinking Water Supply	—	None proposed
Wildlife	—	None proposed
Livestock Water Supply	—	None proposed
Irrigation Water	Total	0.5 µg/L
Primary Contact Recreation	—	None proposed
Freshwater and Marine Aquatic Life - water	Total PCB #105 PCB #169 PCB #77 PCB #126	0.1 ng/L 0.09 ng/L 0.06 ng/L 0.04 ng/L 0.00025 ng/L
Freshwater and Marine Aquatic Life - fish and/or shellfish (for wildlife consumption: whole animal)	Total	0.1 µg/g wet weight
Freshwater and Marine Aquatic Life - fish and/or shellfish (for human consumption: edible tissue only)	Total	2.0 µg/g wet weight
Freshwater and Marine Aquatic Life - sediment (*containing 1% organic carbon)	Total	0.02 µg/g dry weight

1. * If sediment organic carbon is not 1%, the criterion is = (0.02 µg/g) x (% organic carbon content).
Reference 15.

The WWQG contain two tables; table two is exclusively comprised of sediment-associated values. These values do not enjoy the same status as the AWQG, although they MAY be used in the establishment of Objectives.

The use of these WWQG values for sediment is not unequivocal, and the Guideline values cannot be adopted automatically as "target values" or "compliance factors". The Ministry in its introduction to the tables, noting earlier the origin of the values published in these tables, advises the potential user of the following:

"Sediment guidelines are generally stated in two ways:

1. Safe levels of substances, which will protect aquatic life from adverse effects of toxic substances
2. Levels, which if exceeded, will cause severe effects on aquatic life.

These guidelines are not based on cause-effect studies, but on levels of toxic substances found in the sediment where biological effects have been measured. Caution should be exercised in the application of these guidelines. "

CCME Interim Sediment Quality Guidelines (ISQG) and Probable Effects Levels (PEL) are derived from databases of synoptic chemical and biological (invertebrate community, toxicity test) data (CCME 2003). The ISQG, also known as Threshold Effects Levels (TEL), are concentrations below which effects are rarely observed (generally in less than 10% of situations or locations). The PEL are concentrations above which effects are probable (i.e., usually occurring in ≥50% of studies). The interval between the two (TEL and PEL) is referred to as the Possible Effects Range:

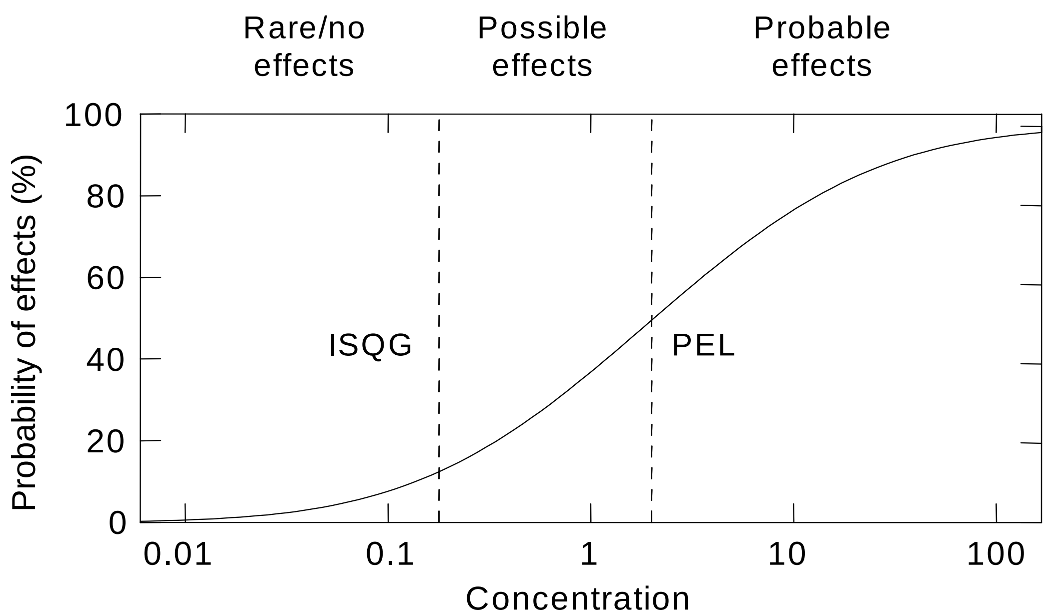


Figure 4 . Possible Effects Range

While the association of values adopted for the effects of man-made anthropogenic substances and environmental quality is relatively clear and simple to understand, the situation is considerably more complex with respect to substances naturally occurring in high concentrations in certain environments. The biota in such locations or situations may either exhibit a degree of adaptation or indeed be or become a specialized biota - unique or uniquely acclimatized to the naturally prevailing condition. Unquestioning application and adoption of the CCME or Working Guideline values would not only be inappropriate in this case, but, should management action be taken to remediate or achieve these values, will also result in potentially irreversible damage to a (unique or locally adapted) ecosystem, which may or may not, apart from its loss, have significant effects on other biotic factors in its vicinity.

This introduces another way of interpreting Figure 4: any line drawn to the right of the TEL or PEL represents a potential change from “standard biota conditions” and in fact may be considered a reflection of the possibility or probability of the creation or existence of a significantly adapted environment with increasingly unique biotic characteristics. The question of whether or not the biota and biotic conditions are sufficiently unique to be of value and to be conserved cannot be addressed by the observation or adoption of Sediment Quality Values or Guidelines. An adequate response is exclusively in the domain of a (benthic) biota assessment and consideration of effects at higher trophic levels. Essentially, the question becomes a value judgment, the complexities of which have been discussed elsewhere (Appendix B).

The potential beneficial effects of riverine sewage deposition, an otherwise undesirable human action, have been convincingly shown in a recent paper by de Bruyn *et al.* (2003). The study considered the role of sewage as a resource for the littoral food web of the fluvial St. Lawrence River near Montreal, Quebec, and revealed a substantial uptake of sewage-derived resources within the plume, up to 10 km from the outfall. Sewage enrichment was shown to stimulate increases in daily fish production based on algivory-detritivory (1.3- to 4.4-fold), invertivory (1.7- to 10-fold), and piscivory (11- to 73-fold). Overall discharge of sewage-derived resources was sufficient to support an overall fivefold increase in secondary production relative to sites outside the plume.

An example of a change from "standard conditions" relating to natural phenomena is the area of the Endeavour Hot Vents, recently designated as a Marine Protected Area. Based on sediment Guidelines alone, this area would almost certainly qualify for remediation.

Notwithstanding the above, the implications of the preceding discussion are important. Where sediment quality values are introduced as a means of monitoring discharges or the effects of anthropogenic substances on an environment, primary consideration is given to the existing conditions, and effects are placed within the context of the ambient environment. Mere application of sediment quality values irrespective of the local circumstances may be inappropriate and unattainable, and may cause severe and irreversible damage to local unique ecosystems.

Therefore, the adoption of a set of values as criteria for protection of the environment requires a thorough assessment or understanding of the ambient environment and the existing biotic conditions of both the ambient and target (receiving) environments. These investigations must be carried out in situ; a literature investigation and associated generalizations about the likely or desirable state of the environment are patently insufficient.

Having recognized the prerequisite for such an investigation, two major problems arise, which will have to be overcome, irrespective of whether Objectives or Guidelines apply. The first, which may or may not be simple, as will be described later in the case of Lions Gate, is to delineate the area likely to be impacted, affected or under the potential influence of a discharge. Mere demarcation based on likelihood and numerical methods (e.g. modeling) are not sufficient; the influence of the discharge must be detectable and preferably “visible” in some form so that a gradient for monitoring can be established. Therefore, predictive methods must be verified in the field and confirmed.

In this respect, sediment quality factors associated with effluent discharges represent some unique challenges relative to water column factors. Water column factors can or may be considered in conjunction with dilution, and through chemical or bacteriological analysis, the effluent plume in its diluted and diluting nature can be followed; this approach is in principle unsuitable for sediment quality factors. Sediment contributors do not necessarily follow the same path as the effluent plume; they should therefore be considered separately.

Sediment contributors may be present in two forms:

- They may be present as particulate matter, which may be transported or deposited along the effluent flow path in the first instance.

- They may be formed from dissolved matter, either by partitioning to other particles present in the stream or by the formation of particulate matter in the water body due to chemical processes such as changes in pH.

Assuming potential sediment contributors are present in the effluent, they will be subject to differential settlement through particle size differences, differential re-suspension of particles due to current patterns, contributions of other discharges or river sediment load. These are all factors that will heavily influence the ultimate sediment quality, which in addition may vary (frequently), spatially and temporally. Therefore, sediment quality values should be established, preferably, through a gradient design or intimate knowledge of the ultimate area of deposition and fate and effect studies of both constituents, and “diluting” substances such as other sediment loads.

The second, and frequently far more complex problem, is the definition of the ambient environment. Here, the adoption of a gradient design for monitoring purposes, where possible, has distinct advantages. It avoids the discussions and value judgments required in establishing a benchmark for comparison of the environment in question. However, gradient designs are not necessarily as simplistic as is the case for effluent plumes, where the highest concentration will inevitably be at the point of emission from the pipe or diffuser, and will decrease with distance from the discharge point. This is the principle underlying the IDZ or Initial Dilution Zone.

The IDZ from a sediment perspective is frequently a zone of low influence, due to the (initial) velocity of the discharge. With the exception of perhaps the very heaviest particles, the effluent solids often do not begin to settle until some distance from the discharge point. In a relatively unconfined discharge area, such as the open sea, the zone of greatest influence will frequently be well away from the IDZ and preceded by a less influenced zone. The sediment profile at Iona is a case in point and illustrates this particularly well. Topographical features may heavily influence the ultimate deposition zone and the zone of greatest influence in a confined system discharge, such as a riverine disharge. Such features may include riverbanks, obstructions or bifurcations, side channel inputs, bends in the river flow path, sandbanks or other deposited materials and sloughs. Particularly in the case of rivers, these may also be heavily influenced by flow considerations associated with the time of year.

In some locations, the establishment of a gradient design is either impracticable or impossible. This is particularly true where small discharges are involved and/or in heavily mixed locations with counter currents and significant water circulation and mixing. This situation can be exacerbated by additional tidal influences. In such cases, a more general approach to sediment quality values must be taken and a series of monitoring stations established to provide a more general picture of the environment at large. The number and location of these stations is very much dependent on the objectives of the monitoring and management program. An initial survey is undertaken to establish the state of the environment and to establish and confirm the inability of distinguishing a clearly influenced area, and therefore, the inability to establish a gradient design. The results from such a survey may establish that there are few gross differences, but may identify minor differences between areas. Therefore, the tools used for such a survey must be sufficiently sensitive to detect such differences.

Benthic surveys, appropriately designed, may be able to distinguish to a greater or lesser extent differences between areas once confounding factors, such as differences in depth and other inputs, have been eliminated. These differences may then be used as a general partitioning of perhaps somewhat artificial zones and then used for comparison over time. Results from the benthic surveys are correlated with results from sediment chemistry and used for interpretation of the health of the environment. In such a design all stations are presumed to be "in the reference condition" and results from biotic and sediment chemistry surveys are compared to the data collected over time from the station itself and to other stations. This approach has elements of the Environment Canada Reference Condition monitoring approach (reference), albeit applied to a spatially or geographically very limited area. Statistical interpretation of the data generated in this design is very complex, and a convenient and relatively simple means of handling the data and the interpretation is required to ensure that information is useful and manageable.

The requirement to correlate sediment data with biota information is the driver for the Receiving Environment Monitoring approach adopted by the GVRD; however, this condition also imposes a restriction on the monitoring program. Fundamental interpretation of the biotic data is necessary; therefore, a considerably advanced level of knowledge and understanding of both individual organisms and applicable ecosystems is required. If that is not the case, the monitoring program cannot address its primary focus - the "state of health" of the environment - but becomes a "numbers game", a form of "benthic bingo", whereby a score-card is kept without attempting interpretation in the context of the relevant ecosystem.

In practical terms, this restriction is two-fold. The results of the survey are to be interpreted by experts in their field who are familiar with the aspects of statistical analysis and have an in-depth knowledge of community status and structures in the ecosystem under observation. The second restriction is dictated by the first: the ecosystem under observation must be sufficiently well known to allow broad interpretations of its current state and its temporal variability relative to the concepts of stability, decline and improvement.

This then precludes the sampling of both sediments and benthos at great depths, e.g. 250 m; at present, the ecosystem components and function are insufficiently well known to derive useful information applicable to a management program. This applies in particular to the Georgia Strait, primarily those areas close to the current discharges, including areas to the West and Northwest of Point Atkinson. Although the GVRD's (Burd and IOS-assisted and directed) Georgia Strait Ambient Program aims to begin addressing this lack of knowledge (some sampling has already taken place close to the Passage Islands at greater depth), current knowledge is insufficiently advanced to permit direct application of data. Modification of this restriction is the intended result once knowledge and understanding develop; however, the general principle - understanding of the observed environment - will always remain applicable.

Finally, two issues of a practical nature remain: the definition of sediment and the definition of applicable guideline values.

Neither the Objectives nor the Guidelines provide a definition of sediment for the purposes of sediment quality. However, because these Guidelines and Objectives are intended to protect aquatic life, assuming that the values apply to the biologically active layer of the sea or river bottom is considered reasonable. This layer includes the surficial sediments and to some extent the layer subject to bioturbation as both are in direct contact with biota or may release substances that may affect biota. In practical terms, the analysis will be performed on (a portion of) the depth obtained by a van Veen grab. Sediment cores, although important for studying historical deposition and the ultimate fate of constituents as part of GVRD's Ambient Program, will not be used for assessment of the sediment quality values where Objectives or Guidelines apply.

Secondly, the WWQG in particular, make a distinction between marine and freshwater sediments and frequently have differing values associated with these for the same substance. However, there are no such "tailored" values for a "mixed" sediment environment, such as those evident in estuarine and close-coastal environments, partially confined basins and tidal rivers. At Iona, Northwest Langley and possibly Annacis, the situation is reasonably simple and it can be assumed that marine criteria apply to Iona, whereas freshwater criteria apply to N.W. Langley and Annacis despite the intrusion of the saltwater wedge at certain times of the year. Lulu and Lions Gate, however, are less clear-cut; therefore, a decision has to be made concerning the application of criteria. At Lions Gate, the marine criteria are adopted in keeping with the description in the Water Quality Objectives for the Outer Burrard Inlet, and the locality of the discharge. At Lulu, the freshwater criteria are adopted albeit that the works is situated very close to the mouth of the Fraser River. Where individual CSOs and stormwater discharges are considered, similar assumptions would have to be made and stated.

3.2 COLLECTION OF DATA: METHODOLOGY

3.2.1 Station Selection

The purpose of monitoring sediment quality is three-fold:

- To determine whether, or to what extent, effluents and in particular effluent solids affect the local sediment quality
- To determine whether Guidelines or Objectives are exceeded and whether the exceedance is as a direct result of effluent discharges
- To establish correlations, should they exist, between sediment quality and the condition of, or changes in, biota

The outcome of this monitoring therefore could lead to consideration of appropriate management action, where required or desirable. Therefore, sediment quality factors occupy an important place in the series of cautions, warnings and triggers under consideration. However, as single factors, and without reference to biotic factors, they cannot be solely responsible for management action. The scientific basis for this perspective has been recognized and expressed previously (Boyd *et al*, 1998):

"apply a weight of evidence approach for a more balanced assessment of sediment quality, no one benchmark fully assesses potential biological effects".

The implications of this statement are two-fold:

- Exceedance of sediment quality Guidelines and/or Objectives at a given location does not automatically translate into the presence of (undesirable) biological effects and therefore, in itself, does not provide sufficient information to determine a warning status.
- Attainment of sediment quality Guidelines and/or Objectives does not automatically translate into an absence of (undesirable) biological effects, and therefore, should not necessarily be interpreted as an indicator of ecological or community health without regard for results of an associated biota survey.

Both the above statements are fundamental in the proposed "cautions, warning and triggers" approach, which considers the environment and environmental effects in totality, rather than through the application of a single connected factor or several unconnected factors.

A direct linkage between the sediment and biota components of the periodic survey is evident; sediment chemistry must therefore be performed on sediments retrieved from the same area as the benthic grab and vice versa. The selected benthos stations serve a dual role because they function as sediment chemistry stations in the same location and at the same time as benthos samples are taken.

In general, determination of station position is based on known or modeled characteristics of effluent solids deposition. The purpose here is not to sample and analyze the entire area of the (suspected) deposition or zone of influence, but to sample a representative fraction of the area, since the sampling itself is relatively destructive. Excessive sampling results in degradation of the area under study, thereby affecting the capability of subsequent samples to represent environmental effects such as effluent or sediment deposition. In benthic monitoring, three samples are taken per each station location; each sample is treated separately and results are reported by individual grab and later by composites. The samples are usually termed "replicates" although true replication in a non-homogenous environment is not feasible. However, provided the individual sample differences are less than a predetermined percentage, the sample can be accurately termed a replicate to accommodate the monitoring schedule. The potential issue of "pseudo replication" is recognized as a statistical difficulty, equally characteristic of other accepted benthic monitoring programs such as the Environment Canada Pulp and Paper Environmental Effects Monitoring (EEM).

There are a number of possible study designs for selection and installation of stations and these have been well described in the EEM Technical Guidance documents (2002) with consideration of their relative advantages and disadvantages. Five different study designs are recommended, ranging from Single Gradient and Multiple Gradient to Radial and Control Impact designs. The simplest and most straightforward is the 'Single Gradient Design", whereby stations are located in an increasing linear distance from the point of origin of the discharge. This design is suitable for those locations where the effluent (solids) path is relatively well known and where effects, if present, can be monitored to show a decrease relative to increasing distance from the point of origin.

The model functions well for effluents in the water column; essentially, the effluent plug becomes more and more diluted with increasing distance from the discharge point. However, the characteristics of sediment deposition are somewhat unique. Due to the joint effects of initial high velocities, other extraneous factors and differential settlement rates according to particle size differences, a series of zones with unique characteristics may be identified. The Iona discharge illustrates this phenomenon particularly well; heavy, sand-like particles are apparently deposited close to the diffusers, followed by a biotically enriched zone and a moderately impoverished zone with increasing distance from the diffuser (see Chapter 4 – Figure 15). We can assume, based on other characteristics that this is a reflection of particle deposition and in particular, the relative deposition rate of finer organic material. The transect survey undertaken in 2003 confirmed that the 80m contour selected for the monitoring program based on the modeling, is the zone of maximum deposition. Consequently, the single gradient design has been demonstrated to be appropriate for this location.

Where effluent (solids deposition) characteristics differ from the modeled characteristics (and to the extent that a clearly influenced and uniquely identifiable zone is insufficiently detectable), a strategy other than the gradient model is required. Note, however, that a gradient model may still be appropriate for the water column, in which case the monitoring stations for water and sediment/benthos will not necessarily be (all) identical.

Lions Gate and Burrard Inlet (Outer Harbour) illustrate these unique effluent characteristics well. Positively identifying the influenced or affected zone and allocating it to one specific discharge is not possible. The entire water body is affected by (a number of other) factors, the combination of which make it impossible to distinguish one cause of effects from another. It could be argued that in such a case the entire water body is affected and the area should be considered in its entirety. A degree of homogeneity across the entire area would therefore be exhibited. However, differences in sediment chemistry profiles and biota (corrected for depth), lend support to the conclusion that homogenous effects on the entire basin, due to a single or dominant source, are not realistic.

In such a case the “gradient design” cannot be used, or at least not interpreted with ease. Although a number of alternative designs exist, practicality and the requirement to inter-correlate the results of the biota surveys and to correlate results with the sediment chemistry surveys, dictate that the number of locations where monitoring can take place is limited. This applies both to logistical considerations and biological/physical factors, where a depth range from shallow to 120 m deep water occurs rapidly. Biota at 40m depth is not strictly comparable to biota at 80 m and distinctly not comparable to biota at 120 m. Therefore a “radiating design” is adopted whereby stations are placed at specific depth ranges and the distribution of stations is based on known factors including current and effluent plume characteristics. As pointed out previously, this pattern causes considerable complexity for statistical analysis and should not be treated in an identical manner as the gradient design. Each station is individually monitored over time, and the relationship between stations either instantaneously or temporally is also observed; the phenomena of change and rate of change are the tools used for evaluation and decision making.

It is recognized, however, that in such conditions, “change” may be associated with a significant event; once observed and confirmed, a response to change may be somewhat untimely and ineffectual. Therefore, other parameters are considered and included in the “cautions” and are being developed to ensure that a clearer picture of the “state of health” of the environment emerges in time for timely consideration of necessary or desirable management options. This evaluation of other parameters is characteristic of the joint NWRI/GVRD mussel program.
Parameter Selection

A multitude of parameters exist, for which sediment quality can be monitored. For example, Water Quality Objectives are clearly defined and generally limited in scope. These parameters can be analyzed and the likelihood of a given substance being a significant component of a discharge determined. If the substance is recognized as a significant discharge component, it can be included in monitoring initiatives.

Where there are currently benthic programs in existence at the marine discharges, WQO only apply to the Burrard Inlet. The sediment quality parameters are illustrated in Table 16.

Table 16. Sediment Quality Parameters
(Continued page 61)

Sediment Quality Parameter		Incidence of Failure (Phippen 2000)
Total Arsenic	20 µg/g dry-weight maximum in sediment	
Total Cadmium	20 µg/g dry-weight maximum in sediment	
Total Chromium	1.0 µg/g dry-weight maximum in sediment	
Total Copper	60 µg/g dry-weight maximum in sediment	
Total Lead	100 µg/g dry-weight maximum in sediment	
Total Nickel	30 µg/g dry-weight maximum in sediment	
Total Mercury	45 µg/g dry-weight maximum in sediment	
Total Zinc	0.15 µg/g dry-weight maximum in sediment	
Total LPAH	150 µg/g dry-weight maximum in sediment	
Naphthalene	0.2 µg/g dry-weight maximum in sediment (long-term)	10/27
Acenaphthylene	0.06 µg/g dry-weight maximum in sediment (long-term)	7/27
Acenaphthene	0.05 µg/g dry-weight maximum in sediment (long-term)	6/27
Fluorene	0.05 µg/g dry-weight maximum in sediment (long-term)	15/27
Phenanthrene	0.15 µg/g dry-weight maximum in sediment (long-term)	25/27
Anthracene	0.1 µg/g dry-weight maximum in sediment (long-term)	16/27
Total HPAH	1.2 µg/g dry-weight maximum in sediment (long-term)	

Sediment Quality Parameter		Incidence of failure (Phippen, 2000)
Fluoranthene	0.17 µg/g dry-weight maximum in sediment (long-term)	25/27
Pyrene	0.26 µg/g dry-weight maximum in sediment (long-term)	23/27
Benzo(a)anthracene	0.13 µg/g dry-weight maximum in sediment (long-term)	18/27
Chrysene	0.14 µg/g dry-weight maximum in sediment (long-term)	22/27
Benzo-fluoranthenes	0.32 µg/g dry-weight maximum in sediment (long-term)	20/27
Benzo(a)pyrene	0.16 µg/g dry-weight maximum in sediment (long-term)	18/27
Indeno(1,2,3-c,d)pyrene	0.06 µg/g dry-weight maximum in sediment (long-term)	26/27
Dibenzo(a,h)anthracene	0.06 µg/g dry-weight maximum in sediment (long-term)	9/27
Benzo(g,h,i)perylene	0.07 µg/g dry-weight maximum in sediment (long-term)	26/27
PCBs in sediment	0.03 micrograms/g dry-weight maximum	4/7

To date, no analyses for organic substances in the WQO list for the Lions Gate receiving environment monitoring program have been conducted; the first two surveys were focused on the collection of metals, Total Organic Carbon (TOC), particle size, fecal coliform and coprostanol data to determine whether a solids deposition zone could be delineated. However, a survey by Phippen, (2000) carried out on behalf of the BC Ministry of Environment Lands and Parks (MELP), noted that the highest values were generally associated with deep cores, and in particular English Bay/Vancouver Yacht club locations. The third column in Table 17 shows the number of samples taken over the entire Burrard Inlet, which exceeded the sediment quality objective for that particular parameter in Phippen's (2000) survey. The above table clearly illustrates that associated issues are widespread and not confined to the Inner or Outer Harbour, which is particularly evident for PAH.

Phippen (2000) also notes that in many cases the gross exceedances occur in deeper cores; more recent sediment deposition seems to indicate a significant improvement compared to historical deposits. This would suggest a primary historical source or sources of declining activity as opposed to a more constant source as represented by the Lions Gate discharge.

The GVRD 1997 effluent characterization study provides specific data on effluent suspended solids composition. Results for all of the WQO for sediment are present for Lions Gate. These results clearly illustrate that all of the components, with minor exceptions, are present in quantities (microgram/g dry weight) greater than the Objectives. However, areas of significant localized solids deposition would be required in order to cause local exceedance of Burrard Inlet sediment Quality Objectives, particularly for organics. The investigations to date have not identified any such areas within the Outer Harbour. Therefore, from a Lions Gate discharge point of view, analyses for most of these substances may not be directly relevant and could therefore be omitted.

However, from a "state of health of the environment" point of view, acknowledging the paucity of existing data and the necessity to correlate results from the benthic survey with sediment characteristics, analysis for the entire suite is beneficial. Moreover, in combination with future results from monitoring of the Inner Harbour and other locations, these data may facilitate an understanding of the dynamics of sediment deposition and quality, and facilitate determination of the source of constituents. Therefore, in the first instance, sediment quality parameters routinely monitored at benthic station locations will mirror the WQO list for sediment, including TOC for normalization of the organics results. However, any exceedance cannot be automatically attributed to the Lions Gate discharge at this time and is therefore for background information only.

In addition, a number of other parameters are monitored because they are either critical for the proposed "cautions, warnings and triggers" schedule or are required to confirm or eliminate areas under influence of Lions Gate. These include silver, acid volatile sulphide (AVS[1]), fecal coliform, 4 nonylphenol (4-NP) and, until such time as subsequent years' 4-NP data are available, coprostanol, as a temporary substitute.

[1] Acid volatile sulphide is a measure of the weak acid extraction of metal sulphides from sediments. When used as an indicator in this context it is a crude measure of the recent redox conditions in sediments. Certain metals bind preferentially to oxygen to form metal oxides in sediments. When oxygen is depleted in sediments these metals will bind in greater amounts with sulphides forming metal sulphides. The sulphides are contributed by bacterial metabolism of hydrogen sulphide in low oxygen conditions.

At Iona, the situation is less clear; no WQO apply in the receiving environment of the Iona discharge. The WWQG contain some 57 parameters specific to the marine environment, some 50% of which are similar or identical to the WQO for the Burrard Inlet (sediment). However, the values are not necessarily identical and determining which guideline value to adopt may be confusing. For example, the marine sediment guideline values for Endrin, listed in the table, are comprised of three separate guideline values.

Furthermore, a comparison of the WWQG and the AWQG, illustrates that the WWQG limits do not necessarily translate into the same AWQG limits. For example, ISQG and PEL are listed in the WWQG for Anthracene, but no AWQG limit has been set for marine substances due to "insufficient data". Therefore, adoption of the Anthracene value from the WWQG for the purpose of monitoring Iona sediment quality is clearly premature, both from the GVRD's and the Ministry's perspective. While there would be no objection if the substance analyzed is below the WWQG limits, a substance that exceeds these guidelines, for whatever reason, may create the perception that a problem exists. However, this perception would be based on an incomplete evaluation of the applicability of the generic Guidelines. The situation becomes even more confusing where a multiplicity of inputs of the same substance exists, such as in the case of PAH. PCB's are even more complex, as described in Chapter 4. Therefore, adoption of the WWQG within the "warnings and triggers" component of the "cautions, warnings and triggers"framework is clearly premature.

The AWQG are based on more detailed considerations for specific purposes such as the protection of "Aquatic Life"; however, the considerations remain generic in nature. Water Quality Objectives (WQO) are set for specific waters and specific purposes, taking into account local background, historical and current activities and other factors. AWQG criteria are not necessarily lower than cases where WQO have been set, as evidenced by an examination of the PAH AWQG versus the Burrard Inlet WQO (see Table 17).

Table 17. PAH AWQG vs. Burrard Inlet WQO

SEDIMENT PARAMETER MEASURED	AWQG MICROGRAMS/G DRY WEIGHT	WQO MICROGRAMS/G DRY WEIGHT
Naphthalene	0.01	0.2
Acenaphthene	0.15	0.05
Fluorene	0.2	0.05
Chrysene	0.2	0.14
Benzo(a)pyrene	0.06	0.16

Values lower than the AWQG in the WQO have apparently been set from a basis other than the protection of aquatic life, which is the basis of AWQG.

Therefore, the selection of a set of criteria for "compliance" considerations without Objectives in existence becomes extremely difficult. Therefore, monitoring of the current routine suite, albeit with possible modifications after a formal review, will continue; however, the information obtained from the routine monitoring will be allocated a "cautionary" status within the hierarchy of the "cautions, warnings and triggers" framework.

At present extensive efforts are being made by the GVRD to determine the ambient conditions for the Lower Fraser River. This is a necessary precursor to the design of any routine monitoring scheme and the subsequent determination of "cautions, warning and triggers" for sediment. The sediment deposition and movement patterns in the Lower Fraser River are extremely complex and variable, both temporally and spatially. In particular, the freshet sediment load has significant effects on the sediment quality of the Fraser, as does the periodic dredging. Moreover, a multitude of confounding factors are evident in and on the Fraser, some of which include CSOs, storm water overflows, industrial discharges and activities and land drainage. Identification of a solids deposition zone, if it exists, for each of the three WWTPs, is currently a priority, and forms part of the efforts being undertaken to increase understanding of conditions in the Fraser. Following the establishment of such clearly attributable zones, sediment quality will be investigated and monitored in conjunction with the WQO for the relevant stretches of the Fraser River.

Storm water and CSO discharges predominantly occur in environments where WQO apply; these include, for example, Burrard Inlet, Fraser River and Boundary Bay. Historically, a significant amount of investigatory work on possible impact by, in particular, CSOs has been conducted. However, the District and the Municipalities are committed to elimination of CSO events through storm water separation or storage. Therefore, the effects of these discharges are considered temporary and significant progress is underway toward the elimination or reduction of these events. The District will review the outcome of the historical studies and establish a relevant program for monitoring existing effects and subsequent improvements following successful separation of part or all of the storm water from sanitary sewage.

With the exception of the largest of the CSOs, the majority of discharges are not expected to have any significant influence on sediment quality; most discharges are of the overflow- rather than the syphon type. A pilot program will commence in 2004, combining enhanced environmental quality modeling capability with environmental data collection to evaluate the effect of smaller discharges and to assist in the prioritization of disconnections or remedial measures.

The Burrard Inlet Inner Harbour is a complex and highly confounded environment. It is subject to tidal inflow of water containing Lions Gate effluent, but is confounded by industrial activities inside the Inner Harbour, industrial and rural activities in the inflow into the Inner Harbour from the eastern end, including the Port Moody Arm and Indian Arm, and CSOs. The complexity of this environment has been highlighted in the first and second of the Burrard Inlet surveys referred to earlier in this chapter; following discussion with stakeholders and the Environmental Monitoring Committee the decision to consider this environment in a special study was made. This study involves the collating of historical and currently available data, followed by subsequent assessment of the validity and currency of the data, and design of an appropriate monitoring program for implementation once the first and second study phases are completed.

3.2.2 Data Handling and Interpretation

The collection of sediment quality data, based on both the WQO and WWQG, results in a plethora of available data points, both in terms of individual substances and cumulative annual results. Each data point can be examined and trends for individual substances can be determined on a year-to-year basis, both for individual and cumulative stations. Thus a picture of sediment quality can be formed of longer-term trends based on their chemistry. However, this merely determines the "compliance" of the investigated sediments with respect to the individual parameters in the Guidelines or Objectives.

Currently available data show some variation in results of the individual parameters (both statistically significant and insignificant); comparison of the results across the various parameters illustrates that results do not exhibit uniform variation for each parameter in any given sampling period. Samples are taken on an annual basis and because they are taken singly and not over a five-week period, for example, they represent a "snapshot" in time. Comparing the cadmium results from the Outer Burrard Inlet over the two samples taken in the period October and November 2002 illustrates this inherent variation. Some of the results are obviously from highly transient events; sampling at the "wrong" time may result in either misplaced concern or comfort. A single sampling event cannot discern between the two.

The requirement, within the framework of the LWMP, to consider results in terms of "state of health of the environment" adds additional complexities. How does one judge the effect of an increase or decrease in some parameters within the context of an increase or decrease in other parameters? Some correlation between the parameters or some effect on the biota must be identified before action is considered or implemented. However in large, very well mixed environments such as the Burrard Inlet, correlations or effects may occur at a late stage, leading to the potential risk that early warning signs would be missed by the above approach. Therefore, some method of integrating and interpreting the cumulative chemistry results of sediment quality parameters must be adopted to provide the early warning required. The simple consideration of concentrations versus TEL or Objective for individual substance values is insufficient, as additive and antagonistic factors apply.

Paine (2003) proposed a method using Hazard Quotients, and developed a Sediment Quality Index. The work is based on the mean quotient approach described in Long *et al.* (1998) and Fairey *et al.* (2001). Paine (2003) concludes that these indices may be useful summary measures for assessing or summarizing sediment quality, and similar indices are good predictors of biological effects in other studies and sites.

The SQ index and other mean quotients are only meaningful if they are good predictors of the probability and magnitude of biological effects. Figure 5 plots two measures of effects on amphipods in toxicity tests against a mean quotient index developed by Fairey *et al.* (2001).

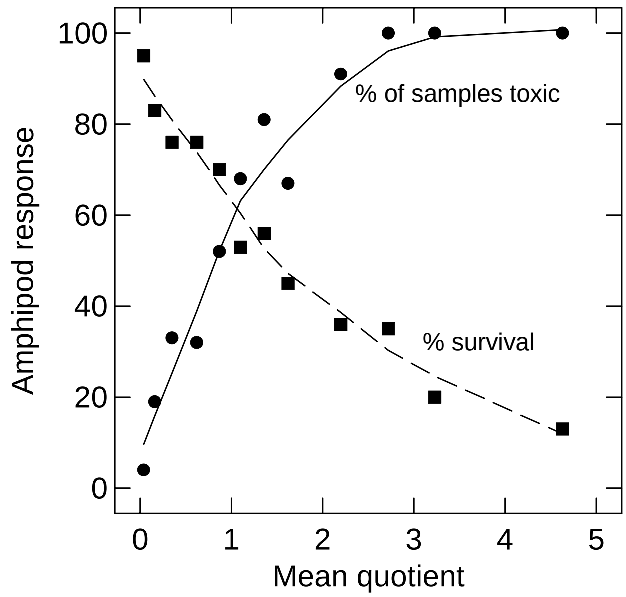


Figure 5. Effects on Amphipods in Toxicity Tests

Fairey's index was based on nine chemicals or chemical groups, and PEL/ERM for seven of those nine chemicals. The index was an excellent predictor of toxicity and effects in 1,692 samples collected from Biscayne Bay (off Miami, FL). Long *et al.* (1998) found a similar relationship between toxicity and other indices based on PEL/ERM for a larger set of chemicals. These relationships generalize the effects ranges in Figure 3 over multiple chemicals, with "mean quotients" replacing concentration as the *X* axis.

Paine (2003) applies the proposed Hazard Quotients (SQV in his case) and Sediment Quality Index (SQI) for a selected number of parameters to the analytical results available for Iona and concludes:

"*Comparison of concentrations to SQV, and SQ index values, suggest that effects of contamination from the discharge (or other sources) should be minimal. Concentrations of most compounds were in the rare/no effects range in Figure 2. "Excursions" into the possible effects range were largely limited to several metals with high background levels, and elevated concentrations of PAH (spikes) that were not easily attributable to the outfall. With the exception of copper, concentrations of the good and equivocal indicators in Table 17 have never exceeded ISQG/ERL when those SQV are available.*

Other studies have shown that CCME or NSTP SQV, especially if combined in mean quotient indices, are good predictors of the probability or magnitude of effects. Conclusions based on comparisons to SQV in this study are consistent with measured biological effects in the benthic invertebrate and tissue residue surveys (Burd 2000, McPherson et al. 2001, 2003; Bailey et al. 2003). Effects on benthic invertebrates and fish/shellfish have been observed that could be attributed to sediment contamination or proximity or exposure to the discharge. However, these effects have been minor or negligible, and in the case of benthic invertebrates, arguably more indicative of enrichment effects than toxicity."

The Hazard Quotient is calculated by dividing the concentration of the substance by the PEL or other selected value such as the Guideline or Objective for the substance. The Sediment Quality Index is then calculated by taking the mean of the Hazard Quotients.

However, Paine's indices, particularly in the case of the Burrard Inlet, were targeted towards a number of components he considered good or potential indicators of a municipal wastewater discharge, and therefore, he does not apply all available values for Guidelines or Objectives but rather, considers discharge-specific effects. Therefore, his calculated indices do not illustrate a representation of the current sediment quality or the sediment quality existing in each of the considered years.

Calculation of the same PEL-based or other indices using a different or expanded set of parameters is possible; these same indices could be used for longer term monitoring purposes. PEL-based indices will provide an assessment of potential biological effects, whereas indices based on other values, such as Guidelines or Objectives provide a measure of the overall sediment quality compared to these target values. Indices can then be used in the monitoring of trends. An important advantage of the use of indices in this manner is that a single elevated or depressed value of one component, such as Cadmium at Lions Gate in October 2002, does not excessively influence the overall assessment of sediment quality; its effect will be evident, but relatively minimal.

In principle, calculation of indices with consideration of all parameters in the Guidelines or Objectives is possible. However, the index number identified must be useable and susceptible to significant movement in one or more parameters. As Paine (2003) has pointed out, the values for organics are usually effectively zero. Therefore, the presence of a large number of these will cause the index value to become very low by virtue of the fact that each parameter added causes the divisor to increase by one also. The purpose of the SQI is to detect and track change. The number value identified should be of such a magnitude and sensitivity that these characteristics (change and magnitude of change, the latter of which is used to derive "rate and direction of change over time") are preserved. Therefore, both the number of parameters and the parameters themselves should be carefully selected.

Where substances are naturally present in high concentrations and in particular where concentrations are higher than the PEL, the calculated SQI refers to "standard conditions" rather than conditions applying to the environment in question. Naturally high concentrations of any naturally occurring substance may result in an acclimatized or unique local biota, as discussed earlier in this chapter. Therefore, such substances should probably be excluded from calculations involving the PEL.

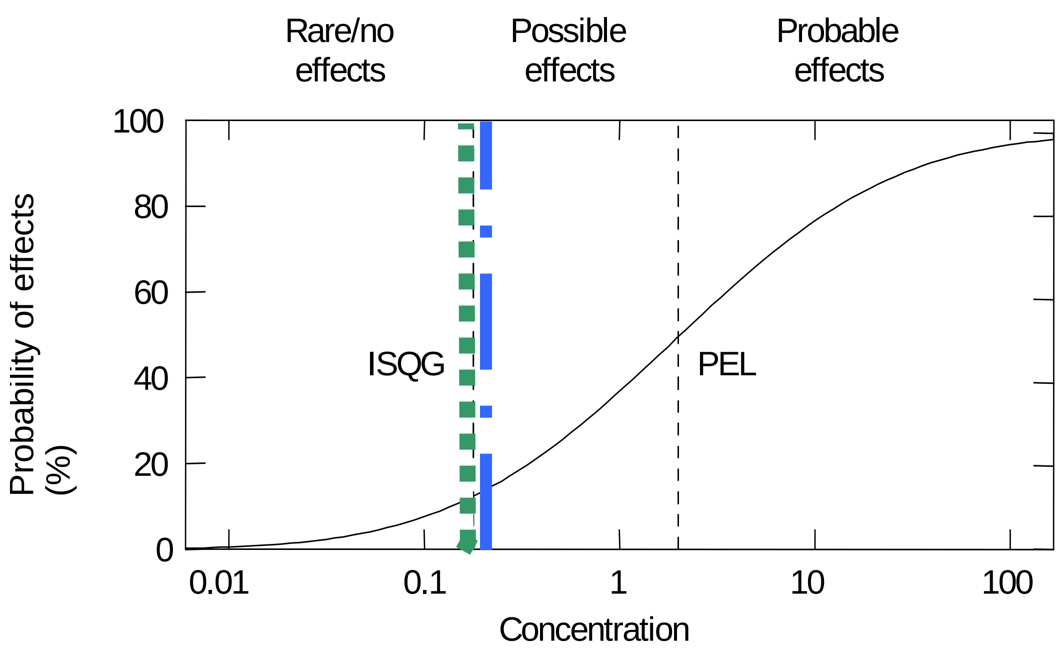
In the local environment of the Georgia Strait and Burrard Inlet, both under heavy influence of the Fraser and its annual sediment load, substances with naturally occurring high concentrations include Copper, Nickel and Arsenic. All three substances have been identified at naturally high levels in the Georgia Strait off Roberts and Sturgeon Banks, and Copper and Nickel at Burrard Inlet. Therefore, the exclusion of these substances from calculations is proposed. Conversely, there are sediment guideline values for Silver in the marine environment (1.0 µg/g dry weight basis, effects range low based on NSTPA; and 2.2 µg/g dry wt., effects range median, also based on NSTPA), but no sediment quality objectives for Silver at Burrard Inlet. Silver, however, is omni-present in wastewater effluent, and most likely should be included in the calculations.

Therefore, the metals selected are Cadmium, Chromium, Lead, Mercury, Silver and Zinc. See Paine (2003), appended to this report as supplementary material, for an in-depth consideration of the various individual metals (Appendix B)

Calculation of the PEL-based SQI for Iona and Burrard Inlet (with some qualifications) based on the metals only and excluding As, Cu, and Ni for Iona and Cu and Ni for Burrard Inlet, generates the plot below, which illustrates that the cumulative values straddle the Threshold Effect Limit:

Note: Iona represented by green line (short dash); Lions Gate represented by blue line (long dash)

Figure 6. Calculations of PEL-based SQI



These results generally agree with the conclusions reached by Burd, McPherson and Bailey as referred to in Paine (2003) and with Paine's conclusion that any effects observed are more likely to be associated with organic enrichment rather than the metal contributions.

Non-PEL based indices can be calculated either by including or excluding the metals naturally present in abundance. The values obtained are, however, not indicative of biological effects, but rather, a measure of "performance" against the adopted standard. This standard may be WWQG or WQO where they apply. Whether or not Copper and Nickel (and Arsenic in the case of Iona) are included is immaterial, because the purpose of this index is to track change over time. In doing so, we can adopt values as cautions or warnings based on mathematical properties where appropriate. For convenience and to facilitate direct comparison with the PEL-based indices, adoption of the same six metals for calculations against the WWQG or Objectives is proposed.

The values applicable to the Guidelines or Objectives are illustrated in Table 18.

Table 18. Guidelines and Objectives for Various Sediment Parameters

Parameter	WWQG	WQO (Burrard Inlet)
Cadmium	0.68 mg/kg sediment dry wt	1 mg/kg sediment dry wt
Chromium	52 mg/kg sediment dry wt	60 mg/kg sediment dry wt
Lead	30 mg/kg sediment dry wt	30 mg/kg sediment dry wt
Mercury	0.13 mg/kg sediment dry wt	0.15 mg/kg sediment dry wt
Silver	1 mg/kg sediment dry wt	1 mg/kg sediment dry wt
Zinc	124 mg/kg sediment dry wt	150 mg/kg sediment dry wt
Arsenic	7.2 mg/kg sediment dry wt	20 mg/kg sediment dry wt

Equally possible is the construction of a table and series of indices for organics as listed in the Guidelines and Objectives and derive some value for these. However, the interpretation of such indices is even more complex than in the case of metals, bearing in mind the requirement that the results must be correlated with the biota surveys. Additive and antagonistic effects are generally less well known and understood than in the case of metals, and therefore, use of such an index as an assessment of the "state of the environment" would be significantly speculative based on current knowledge. Furthermore, the effects of, in particular organics such as PCBs, are frequently not observed "in situ", but rather, at higher trophic levels, which may be either outside of the specific study area or heavily influenced by factors outside the study area. Therefore, the correlation between a local organics index and the general "state of health of the environment" may not apply or may be tenuous at best.

Moreover, in order to arrive at a "workable number", the results will require a different mathematical treatment, e.g. multiplication by a factor of, perhaps, 100 or 1000, and metals and organics indices are therefore not directly comparable or additive.

Although a single or directly comparable set of parameters would be preferable, a combination of the characteristics of substances involved, their existing concentrations, the potential "spread" of the observable effects zones, the different time scales that apply in terms of e.g. acute/subacute effects and bioaccumulation or magnification, and the current state of knowledge regarding additive or antagonistic effects, preclude the development, use and scientific defensibility of such a combined index .

Therefore, it is proposed that the monitoring and interpretation of analytical results for the various organic parameters will continue in the conventional manner allowing consideration of single substances or groups of substances, their concentrations and (rate of) change over time. Where effects or change are observed in the biota surveys, the analyses results will be considered in the special investigations following detection of these effects. Considerations of higher trophic level effects are discussed in Chapter 5.

3.2.3 Iona Area

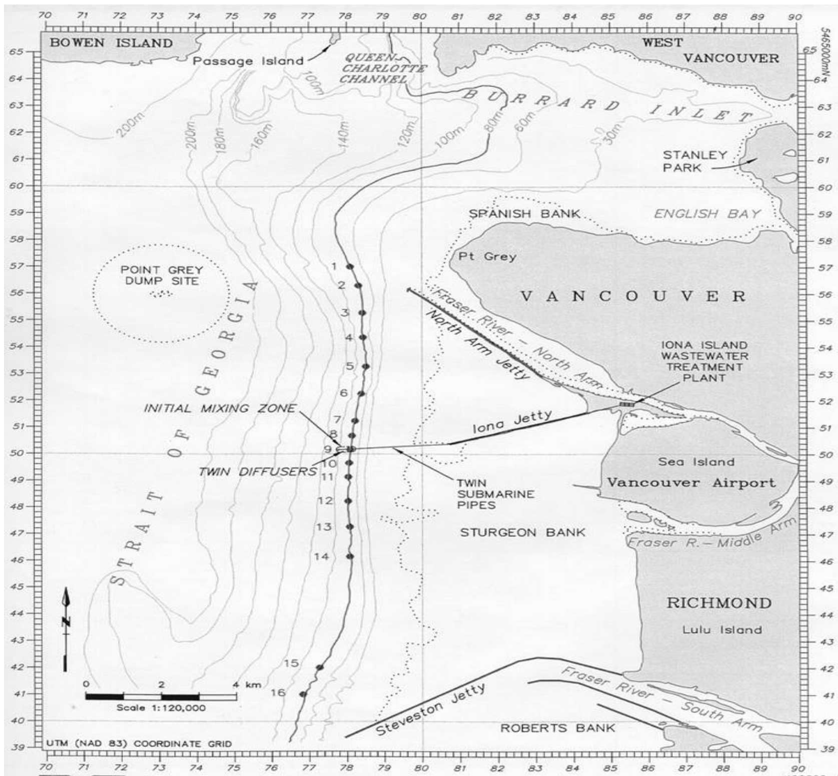


Figure 7. Station Locations for Revised Iona Monitoring Program along the 80 m depth contour

As expressed previously, WQO do not apply within the receiving environment of the Iona discharge. Therefore, the WWQG apply but these will function as “cautions’ rather than warnings or triggers.

The parameters selected for tracking change are based on the six metals. There is in principle no objection to expanding the set with Copper, Nickel and Arsenic, or indeed the inclusion of selected organic parameters. However, to facilitate comparability with PEL-based indices, and to maintain the derived indices of a useful magnitude to track change, if any, the inclusion of all organic parameters is not recommended.

Parameters not included in the calculated indices are not ignored; the existing full suite of analyses will continue and each result is evaluated based on statistical significance or lack thereof. However, unless evidence suggests the inclusion of other parameters, the SQI will consist of the six selected metals: Cd, Cr, Pb, Ag, Hg and Zn to determine overall change.

The results for each station are examined singly and in conjunction with the cumulative station performance. Cumulative station performance will be assessed both with and without the reference stations, so that changes in ambient conditions are considered in the overall interpretation.

Acknowledging the existence of temporal and spatial variation, any change in the calculated index is not necessarily significant. Therefore, some limits are required to set levels that initiate more detailed investigation. Four years of monitoring data are available for the Iona area; upon careful examination, the suggested appropriate limit is the annually calculated SQI + twice the Standard Deviation. Based on these parameters, Table 19 can be constructed, providing limits for each station, in addition to the cumulative stations with and without the reference stations.

Table 19. Station Limits

Iona		**2000** SQI	**2001** SQI	**2002** SQI	**2003** SQI	1*SD	**current SQI av.4 years**	**SQI+2SD**
STN 1	(6.8 km N)							
ISQG		0.41	0.35	0.34	0.34	0.034	**0.36**	**0.43**
PEL		0.16	0.14	0.13	0.13	0.014	**0.14**	**0.17**
STN 2	(6.1 km N)							
ISQG		0.46	0.43	0.42	0.40	0.025	**0.43**	**0.48**
PEL		0.18	0.17	0.16	0.15	0.013	**0.17**	**0.20**
STN 3	(5.1 km N)							
ISQG		0.61	0.62	0.57	0.57	0.026	**0.59**	**0.64**
PEL		0.24	0.24	0.22	0.21	0.015	**0.23**	**0.26**
STN 4	(4.2 km N)							
ISQG		0.61	0.66	0.57	0.57	0.043	**0.6**	**0.69**
PEL		0.25	0.26	0.22	0.22	0.021	**0.24**	**0.28**
STN 5	(3.1 km N)							
ISQG		0.69	0.64	0.62	0.64	0.030	**0.65**	**0.71**
PEL		0.28	0.26	0.24	0.24	0.019	**0.26**	**0.30**

Table 19 continued

Iona		**2000** SQI	**2001** SQI	**2002** SQI	**2003** SQI	1*SD	**current SQI av.4 years**	**SQI+2SD**
STN 6	(2.1 km N)							
ISQG		0.70	0.69	0.67	0.64	0.026	**0.68**	**0.73**
PEL		0.28	0.27	0.26	0.25	0.013	**0.26**	**0.29**
STN 7	(1.1 km N)							
ISQG		0.70	0.74	0.67	0.65	0.039	**0.69**	**0.77**
PEL		0.27	0.29	0.26	0.25	0.017	**0.27**	**0.30**
STN 8	(0.5 km N)							
ISQG		0.63	0.71	0.67	0.62	0.041	**0.66**	**0.74**
PEL		0.25	0.28	0.25	0.24	0.017	**0.25**	**0.28**
STN 9	(Diffusers)							
ISQG		0.58	0.51	0.51	0.50	0.037	**0.52**	**0.59**
PEL		0.23	0.19	0.19	0.18	0.022	**0.2**	**0.24**
STN 10	(0.5 km S)							
ISQG		0.59	0.55	0.48	0.57	0.048	**0.55**	**0.65**
PEL		0.23	0.20	0.18	0.21	0.021	**0.2**	**0.24**
STN 11	(1.0 km S)							
ISQG		0.60	0.51	0.47	0.53	0.054	**0.52**	**0.63**
PEL		0.23	0.20	0.17	0.19	0.025	**0.2**	**0.25**
STN 12	(1.9 km S)							
ISQG		0.56	0.53	0.47	0.47	0.045	**0.51**	**0.60**
PEL		0.21	0.20	0.17	0.18	0.018	**0.19**	**0.23**
STN 13	(2.9 km S)							
ISQG		0.59	0.55	0.49	0.51	0.044	**0.53**	**0.62**
PEL		0.21	0.20	0.17	0.18	0.018	**0.19**	**0.23**
STN 14	(4.0 km S)							
ISQG		0.58	0.52	0.51	0.46	0.049	**0.52**	**0.62**
PEL		0.22	0.20	0.18	0.17	0.022	**0.19**	**0.23**

Table 19 continued

Iona	**2000** SQI	**2001** SQI	**2002** SQI	**2003** SQI	**1*SD**	**current SQI av.4 years**	**SQI+2SD**
STN 15 (8.2 km S)							
ISQG	0.50	0.43	0.44	0.47	0.032	**0.46**	**0.52**
PEL	0.18	0.16	0.15	0.16	0.013	**0.16**	**0.19**
STN 16 (9.2 km S)							
ISQG	0.46	0.43	0.42	0.47	0.024	**0.45**	**0.50**
PEL	0.16	0.16	0.14	0.15	0.010	**0.15**	**0.17**
Cumulative Stations 1-16							
ISQG	0.58	0.55	0.52	0.53	0.026	**0.54**	**0.59**
PEL	0.22	0.21	0.19	0.19	0.015	**0.21**	**0.24**
Cumulative Stations excl 1,2,15,16							
ISQG	0.62	0.60	0.56	0.56	0.030	**0.58**	**0.64**
PEL	0.24	0.23	0.21	0.21	0.015	**0.22**	**0.25**

Figure 8, below, represents the current (2003) SQI for PEL and ISQG and compares the two indices. The known effluent solids deposition pattern and the effect zones can be clearly distinguished. In principle this approach can be subjected to further advanced statistical analysis and correlation with the effect zones as delineated in the benthic surveys investigated. This is currently being explored further, the aim being to develop a statistically rigorous analysis of patterns and effects exposed across the two components (benthic and sediment) of the annual Iona survey.

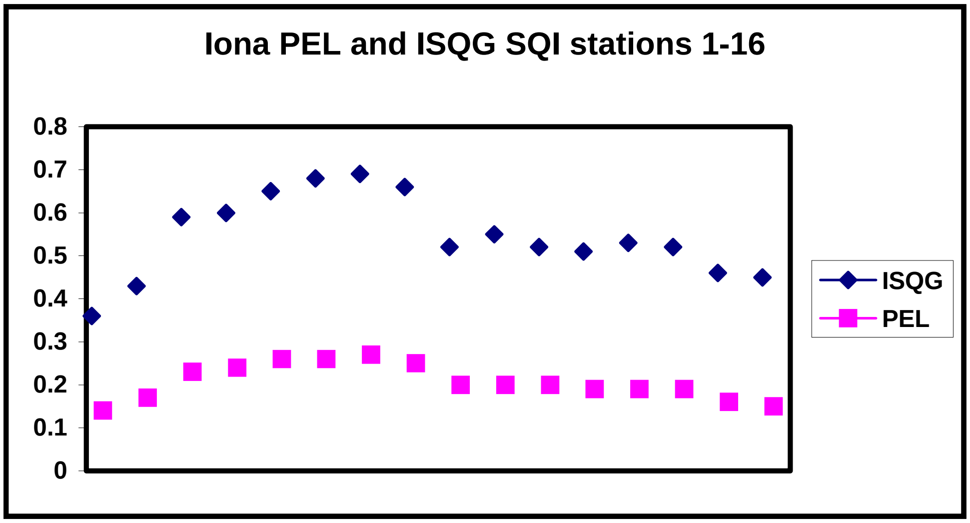


Figure 8. Iona PEL and ISQG SQI Stations 1-16

Response

As explained previously, the WWQG and appropriate AWQG are adopted for the Iona area as "cautionary"; no applicable WQO exist in the receiving environment of the Iona discharge.

The proposed SQI values are calculated annually for each of the stations and the cumulative stations. These values are calculated both using PEL and using the WWQG/AWQG where appropriate (represented as ISQG in the table). The annual values are compared to the "limit value" of the annual average SQI + twice the standard deviation. Should the limit value be exceeded on any one or multiple stations, the individual Hazard Quotients are analyzed and the substance or substances causing the increase in the SQI identified. Unless obvious and substantial discharge-related factors exist, and changes in the biota as per the "warning" or "trigger" benchmarks are evident, no further immediate action is taken because the phenomenon may be of a transient and temporary nature.

If the subsequent year's sampling program identifies a further or sustained increase in the SQI values compared to the applicable limit values, an investigation of the cause of the increase will be undertaken if the component (HQ) or components (HQs) causing the increase are likely attributable to the discharge. The investigation may consist of special studies or, if considered of value based on the information available, of redirected or expanded existing studies, such as the Georgia Strait Ambient Program.

If the information derived from the sediment monitoring program or the special studies coincides with a change in the biota as described in Chapter 4, or demonstrably suggests a likely change occurring in the near future at the "warnings" or "triggers" level in the benthic component, action taken will be consistent with those described in the benthic warnings and triggers (see Chapter 4).

Monitoring of data emanating from the organic analyses of the Iona area sediments will continue as described elsewhere in this section and consistent with current methodology in the annual Iona surveys. Trends will be characterized and monitored. At present, trace organic data alone cannot be cause for action, unless evidence of a substantial effect uncontrovertibly associated with the discharge is identified. Note will be taken of studies conducted by others in the area in the consideration of potential cause and effect.

Collection of data for other parameters, including coprostanol and 4-Nonylphenol as good discharge indicators, and Total Organic Carbon and Acid Volatile Sulphide will continue; these substances are instrumental in the interpretation of collected data and in satisfying requirements of the "warnings and triggers" process.

Integration of the analytical results for trace organic and other substances in a scientifically and statistically rigorous manner for the purposes of exploration and extrapolation of effects on the "state of health of the environment" is intended. Efforts to establish a rigorous methodology are ongoing.

3.2.4 Burrard Inlet (Lions Gate)

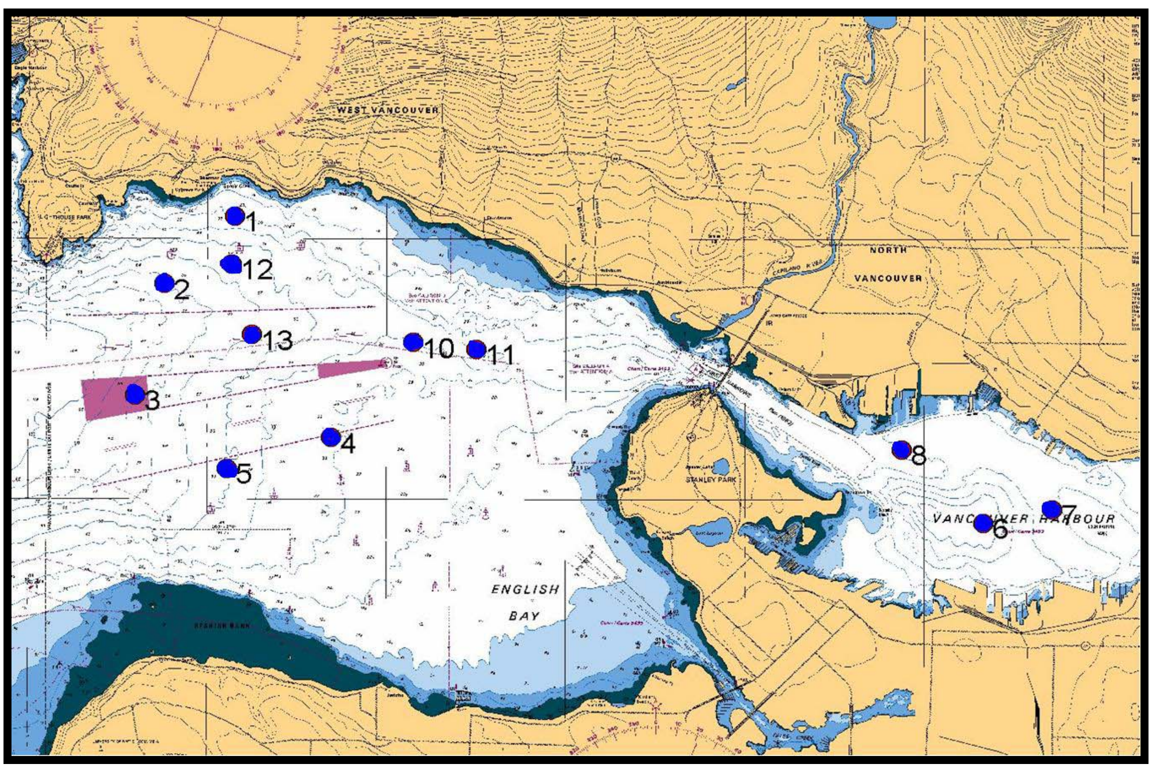


Figure 9. Burrard Inlet (Lions Gate)

Unlike the Iona area, Water Quality Objectives apply to the Burrard Inlet. The Burrard Inlet has been divided into six sub-basins; separate WQO apply to each of these basins. The criteria applicable directly to Lions Gate are those associated with the Outer Harbour.

As acknowledged, some of the Lions Gate effluent, at certain stages of the tide, will be directed towards the Inner Harbour. However, in another forum, the Environmental Monitoring Committee (EMC), the Inner Harbour was acknowledged to represent an extremely complex environment with many confounding factors and influences. This area warrants a special study before any conclusions can be drawn regarding the potential influence of Lions Gate WWTP on this environment. Phase One of this study - the data inventory - has been initiated and, once the study has been completed, it will be assessed to determine to what extent the "cautions, warnings and triggers" process can or should be extended towards the Inner Harbour.

The Lions Gate WWTP discharges into the Outer Harbour and has been designated in the Water Quality Objectives for the Burrrard Inlet; therefore, the sediment monitoring program concentrates on the Outer Harbour. Nevertheless, some data collection on Inner Harbour Stations 6, 7 and 8 will continue.

The monitoring program for Lions Gate is a newly established program relative to the mature Iona monitoring program. Preliminary work was carried out in the period 1999-2001, which included near field surveys and the production of an effluent circulation and an effluent solids deposition model. In October 2002, the first of two reconnaissance surveys was carried out. The purpose of this survey was to obtain a clear insight into the structure and habitat of the Outer Harbour benthos. Sidescan Sonar and video camera surveys were undertaken in the areas identified in the solids deposition model as having the potentially greatest solids accumulation. A benthic biota survey was then planned, the stations of which were to be confirmed following the sidescan and video components.

That the areas identified in the model were not in fact areas of significant deposition soon became evident, and the benthic survey station design had to be modified to reflect these findings. 10 Stations were initially identified, but there was either no, or insufficient sediment at Stations 7,8 and 9 to enable grab samples. Station 9 was bare rock and was thus eliminated entirely from the survey; Stations 7 and 8 yielded enough sediment to permit sediment chemistry but were unsuitable for biota sampling.

When it became clear that there was insufficient evidence for the existence of a gradient, a radial design was adopted. Although Control Impact design was considered, establishing a reference or control site in this environment would be extremely difficult.

The second survey, November 2002, was undertaken to attempt identification of areas where solids deposition was occurring. Despite the employment of a sampling grid of 40 stations, very little evidence presented itself, leading to the conclusion that the Outer Harbour is an extremely mixed and circulating environment. No evidence of Lions Gate solids deposition, significant or otherwise, could be collected. Limited chemistry, including metals, TOV and Coprostanol, was performed on the collected sediments in addition to Fecal Coliform. No organics data were collected. A relatively comprehensive assessment of sediment quality in the Outer Harbour resulted, due to size of sampling grid (40 stations) and sampling frequency (one month separation) employed. Results of these surveys, and the following March 2003 survey, have been used by Paine (2003) in his consideration of sediment Objectives for the Outer Harbour. A more comprehensive GVRD report for the fall 2002 surveys will be issued in mid 2004.

The survey highlighted the spatially variable nature of sediment metal content and detected a highly temporal event in one particular case (Cadmium on three stations). This exposes a weakness in methodology if only one sample taken per annum is assumed representative of the overall condition.

Combination of all exceedances for sediment quality versus the WQO yields Figure 10:

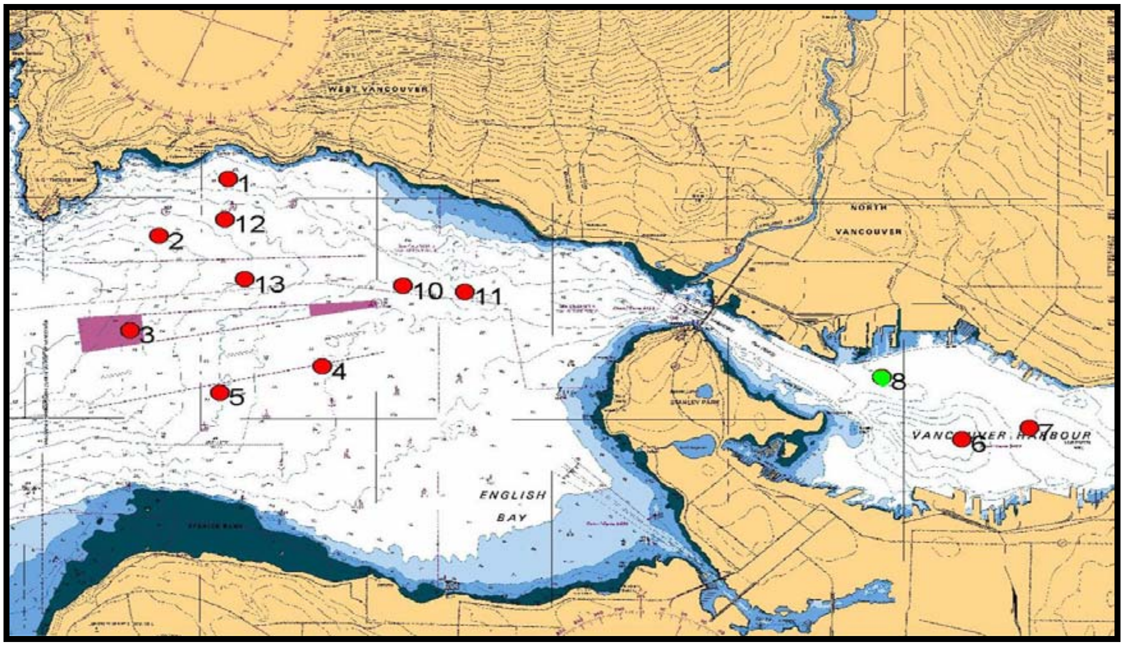
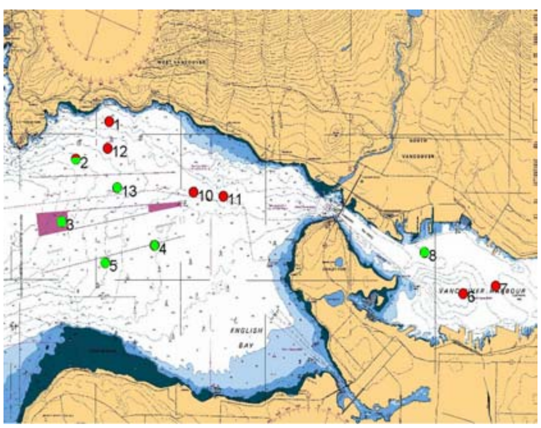
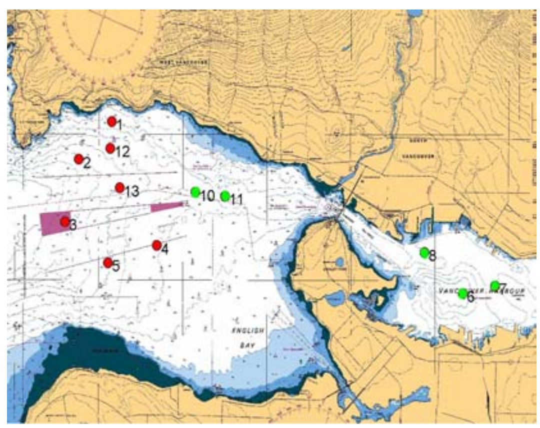


Figure 10. Sediment Quality Exceedances at Burrard Inlet (Lions Gate)

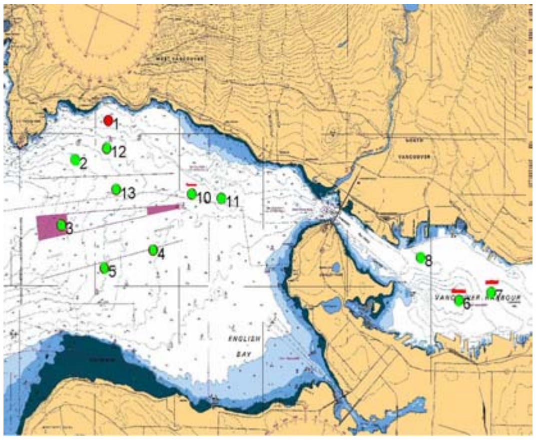
However, Figure 11 (a through d) illustrates the situation when various metal parameters are considered singly.



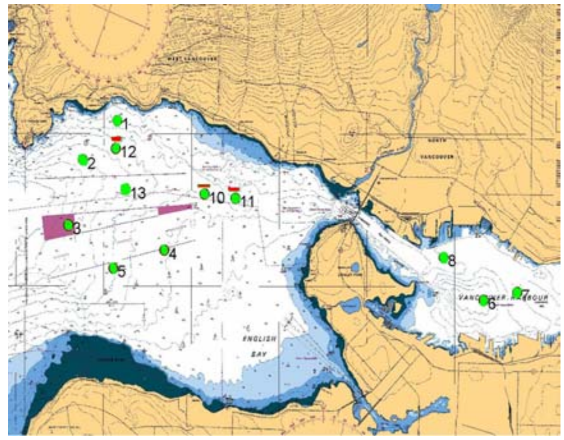
Copper (a)



Nickel (b)



Mercury and Lead (c)



Cadmium (d)

Figure 11. Sediment Quality Exceedances of Individual Metal Parameters (a through d)

The stations marked in red are those where the concentration of the given metal exceeds the WQO for that metal in sediment. Stations marked with a red "bar" are stations where the value was exceeded on one, or rarely two, of three sampling events.

Figure 11 illustrates that metal concentrations are highly variable and to some extent localized phenomena. Nickel appears to be a western Outer Harbour factor, whereas copper would appear to be a more widespread, but predominantly northern factor.

Only station 1 features consistently in almost all parameters measured. Station 1 also had a significantly different biota compared to other Outer Harbour Stations. Within that context, Station 1 has been identified as an anomaly, and will be investigated in greater detail in 2004/5. Station 6 is within the Inner Harbour and will not be considered further in this discussion.

In principle, a similar table to Iona can be constructed for Burrard Inlet and Lions Gate. However, only very limited data are currently available for this area. Only three surveys have been undertaken to date, two of which were in the Fall, and the third one was in the Spring; the next survey is scheduled for March/April 2004. Therefore, at present, there are insufficient equivalent data points (Fall Or Spring) for the determination of "limit values" using the same methodology as used at Iona; i.e., the current average SQI + 2*Standard Deviation. The intention is to allow the sediment quality data collected in this program to function as "warnings" rather than "cautions" using the SQI approach because WQO rather than WWQG apply to the Outer Harbour.

Therefore, collection of data points to facilitate the derivation of scientifically and statistically rigorous treatment and the determination of meaningful Standard Deviations is considered a priority.

Table 20. Sediment Quality Indices at Burrard Inlet (Lions Gate)

	All 9 Metals	Excl. Cu Ni
Station 2		
WQO	0.72	0.64
PEL	0.41	0.27
Station 3		
WQO	0.65	0.58
PEL	0.37	0.25
Station 4		
WQO	0.62	0.56
PEL	0.35	0.23
Station 5		
WQO	0.57	0.51
PEL	0.33	0.22
Station 10		
WQO	0.75	0.69
PEL	0.41	0.28
Station 11		
WQO	0.82	0.77
PEL	0.43	0.3
Station 12		
WQO	0.81	0.74
PEL	0.45	0.3
Station 13		
WQO	0.66	0.6
PEL	0.38	0.26

However, other differences are noted between Iona and Burrard Inlet. A sediment effects profile can be plotted at Iona because monitoring is based on a gradient design; however, due to the modified radial design adopted at Lions Gate and the Outer Harbour, plotting a sediment effects profile is not feasible.

However, through adoption of the SQI approach, an initial distinction based on current information for two groups of stations, is possible. At this stage, these groups are not necessarily the groupings identified in the benthic program, but may serve as a working hypothesis for future development and refinement as data are obtained. Results may be correlated in detail with multi-year data from the benthic program. For the purposes of the working hypothesis, the Northern Stations are considered “exposed” whereas the Southern Stations represent a potential collective reference area.

Table 21. Sediment Quality Indices at Burrard Inlet (Lions Gate)

	WQO all 9 metals	WQO excl Cu Ni	PEL all 9 metals	PEL excl Cu Ni
North	**0.77**	**0.71**	**0.43**	**0.29**
Station 2	0.72	0.64	0.41	0.27
Station 10	0.75	0.69	0.41	0.28
Station 11	0.82	0.77	0.43	0.3
Station 12	0.81	0.74	0.45	0.3
South	**0.63**	**0.56**	**0.36**	**0.24**
Station 3	0.65	0.58	0.37	0.25
Station 4	0.62	0.56	0.35	0.23
Station 5	0.57	0.51	0.33	0.22
Station 13	0.66	0.6	0.38	0.26

Response

Water Quality Objectives apply to the Outer Harbour, as explained previously.
The proposed SQI values are calculated annually for each of the stations, which are considered in the "reference condition". SQIs are also calculated for the two groupings - Northern and Southern Stations - to determine whether the current trend is maintained and whether the Southern Stations, with or without amendment, have utility as a collective reference group. These values are calculated both based on PEL and based on WQO as appropriate. Annual values are compared with the "limit value", which consists of the annual average SQI plus twice the standard deviation once a minimum of four equivalent data points has been collected. Consideration is given to the use of both the fall and spring survey results as "equivalent data points" in the interim, if the standard deviation between these points were within acceptable limits. Should the limit value be exceeded on any one or multiple stations, the individual Hazard Quotients are analyzed and the substance or substances causing the increase in the SQI identified.

If the identified substance(s) is(are) potentially attributable to the Lions Gate discharge, confirmation of the values obtained is undertaken and an increased sampling and analysis program is initiated, enabling the calculation of a "geo-mean" over an extended period. The period envisaged is a five-week survey as referred to in the Water Quality Objectives for Burrard

Inlet, but discussions will be held with the Ministry staff to determine the most suitable form of such an extended survey.

If the extended sampling program identifies a further or sustained increase in the SQI values compared to the applicable limit values, an investigation of the cause of the increase will be undertaken if the component (HQ) or components (HQs) causing the increase are likely attributable to the discharge. The investigation may consist of focused special studies or, if considered valuable based on the information available, of redirected or expanded existing studies, such as the ambient programs for Burrard inlet and the Georgia Strait. Should the information obtained establish that the cause of the elevation in concentrations is the Lions Gate discharge or another discharge from a GVS&DD installation, the trends would be determined and potential mitigating actions identified and evaluated, consistent with the LWMP process. If the information derived from the sediment monitoring program or the special studies coincides with a change in biota as described in Chapter 4, or demonstrably points towards a likely change occurring in the near future at "warnings" or "triggers" levels in the benthic component, action will be taken in accordance with those described in Chapter 4.

The Lions Gate receiving environment monitoring program will, beginning with the March/April 2004 survey, collect sediment organics data for the parameters listed in the WQO for Burrard Inlet (Outer Harbour). Trends will be established and monitored. At present, organics data alone will not instigate action, unless evidence of a substantial effect and indisputable association with the dischargeare identified. Other studies in the area will be considered for potential identification of cause and effect. These studies include the joint GVRD/NWRI mussel program.

Collection of data for other parameters, including coprostanol and 4-Nonylphenol as good discharge indicators, and Total Organic Carbon and Acid Volatile Sulphide will continue; these substances are instrumental in the interpretation of the collected data and in fulfilling requirements of the "warnings and triggers" process. Integration of analytical results for trace organic and other substances in a scientifically and statistically rigorous manner is intended. Successful integration of results will facilitate the exploration and extrapolation of effects on the "state of health of the environment". Efforts to establish a rigorous methodology to accommodate this intention are ongoing.

CHAPTER 4.

BENTHOS

4.1 INTRODUCTION

The purpose of this warning and trigger framework is to develop a means of assessing risk from the discharge to the receiving environment health, including benthic communities, fisheries and higher trophic levels (including humans). Responses to changes in environmental condition related to the discharge must be ecologically sound, and socially and economically responsible.

Biotic indicators in the environment are the only indicators that integrate the exposure, long-term, chronic and acute effects of effluent constituents from wastewater discharges. Since the health of the receiving environment is to be protected, the condition of organisms that must live, grow, reproduce and feed higher trophic levels is the best gauge of ecosystem health.

There are many trophic levels and complex interactions within an ecosystem, but the marine benthos encompasses a range of organism sizes and trophic levels and provides the most direct target for the settlement of particulate materials from municipal liquid waste discharges. Ultimately, most of what is discharged into marine systems through wastewater outfalls will end up precipitating to the sediments. The sessile organisms inhabiting these sediments mostly settle as juveniles, and live out their entire lives within a very small radius of their original settlement location. Thus, over time, they must cope with whatever settles in their habitable space.

The infaunal benthos which can be sampled with a regular grab (about $0.1m^2$ surface area) and screened with a 1 mm sieve tend to be numerous and diverse in marine sediments, and thus amenable to statistical analyses of distributional patterns. They have a life span of about 1-5 years, with most species living 1-2 years and spawning annually. For this reason, changes in the species associations and distributional patterns of these fauna can be readily identified and understood using an annual monitoring program.

4.2 CRITERIA FOR SELECTING INDICATORS AND LEVELS

In order to be useful as tools to help determine how the receiving environment is assimilating and being affected by municipal liquid waste discharges from the marine wastewater outfalls, any exposure, warning or trigger indicators selected must meet a set of conditions. These conditions determine how specific the factor is to the discharge in question, how it is affected by ambient or confounding conditions in the region, and what it tells us about the “health” and assimilative capacity of the receiving environment. Following is a list of issues and questions, which must be addressed during this selection process.

1. *How are biotic and abiotic indicators used in this context?*

   Ultimately, the adverse changes to living organisms are of concern in managing wastewater discharges. In a receiving environment program, measuring these changes directly may be possible, such as in benthic infaunal or sessile epifaunal communities. For these components of the ecosystem, biotic indicators may be used for warning and trigger levels.

However, directly measuring effects on the more widespread and mobile higher trophic levels of the ecosystem with any degree of statistical or ecological confidence is not always possible. However, a wealth of environmental and laboratory research suggests strong and probable links between abiotic indicators of contamination and higher trophic level effects, OR between known biotic effects and probable higher level trophic effects. This is particularly true for such historical contaminants as TBT's, PCB's and DDT and derivatives. These may be selected as warning or trigger indicators[2], even though determining levels at which biotic effects occur is difficult.

In situations where biotic effects of concern are probably occurring but cannot be measured with any accuracy, the warning and trigger levels for associated biotic or abiotic indicators must be estimated. This can be done statistically for the indicator to be used, or may be based on existing guidelines or toxicity data, or on information from other jurisdictions or scientific literature. For example, if sediment geochemistry is adversely affected for a broad area overlapping important fish nurseries or refugia (such as eel-grass beds), it is highly probable that those fisheries stocks inhabiting the area will be impoverished. If these are undesirable effects, the abiotic indicator, which relates to them (or some reliable covariate) may be selected as a candidate warning indicator, with changes in magnitude and extent potentially resulting in a trigger even if there are no statistically measurable biotic effects of concern. In this case, the importance of the specific habitat is the issue of concern.

2. *What are we looking for in the receiving environment?*

Although this issue seems strait-forward enough, some carefully thought-out constraints must be placed on the character and extent of effects in the receiving environment, which are ecologically significant to the ambient biotic community and/or potentially hazardous to fish and mammalian (including human) health. In other words, the types and spatial extent of effects of concern related to the discharge must be identified and prioritised. Various jurisdictions have set out general objectives for compliance of discharges with water and sediment quality in the receiving environment. In Canada, we have the Fisheries Act (2000, c. 7, s. 23. FISH HABITAT PROTECTION AND POLLUTION PREVENTION: 34. (1) For the purposes of sections 35 to 43 – see URL http://laws.justice.gc.ca/en/F-14/54991.html) which prohibits:

(a) any substance that, if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is

[2] Caution is indicated in that the particular abiotic factor must be examined in the context of regional levels, cycling and partitioning. As such, there may be situations where eliminating a known toxicant from the outfall effluent will not effectively change the regional budget for this toxin, but may simply change the recycling dynamics with unlikely net positive effects (Dr. Robie MacDonald (Institute of Ocean Sciences), pers. Comm. - see also Appendix E)

likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water, or

(b) any water that contains a substance in such quantity or concentration, or that has been so treated, processed or changed, by heat or other means, from a natural state that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water

An example for Southern California (Orange County District's discharge permit –see OCSD 2000) includes the following relevant criteria:

D.1.c4. "The rate of deposition of inert solids and the characteristics of inert solids in ocean sediments shall not be changed such that benthic communities are degraded"

D.1.d3: "The dissolved sulfide concentration of waters in and near sediments shall not be significantly increased above that present under natural conditions"

D.1.d4: The concentration of substances, set forth in Table B of the Ocean Plan, in marine sediments shall not be increased to levels which would degrade indigenous biota"

D.1.d5: "The concentration of organic materials in marine sediments shall not be increased to levels which would degrade marine life"

D.1.e1: "Marine communities, including vertebrate, invertebrate and plant species shall not be degraded"

3. *What types of indicators are consistent and predictable enough to use for this purpose?*

a) global experience, other jurisdictions (particularly west coast N. America)
b) indicators specific to wastewater effects
c) indicators with a long-term presence in the area
d) indicators which are not sensitive to a range of natural and anthropogenic effects
e) indicators which are not too variable or patchy spatially or temporally to use with reliability
f) discharge rate or composition (effluent characterization)
g) changes in outfall configuration

4. *What are the constraints on using these indicators?*

a) depth
b) substrate type
c) rate of natural vs wastewater sedimentation
d) natural sediment reducing conditions
e) persistence of the indicator in sediments (see Maldonado et al. 2000)
f) how long does the factor persist in sediments (oxic vs anoxic) and thus is it a short-term, intermediate-term or long-term deposition indicator (Burd, 2000)

5. *What is the natural variability in the area of interest for the appropriate indicators?*

6. *Potential confounding influences that must be taken into account, such as:*

   a) Bottom fishing – (see Burd 2000 for review biotic effects related to bottom fishing) – tends to selectively decimate the larger, surface-exposed forms as well as amphipods, which are epi- or near-bottom feeders and sensitive to physical disruption
   b) Ocean dumping – smothering (like tailings) as well as concentrated contamination from metals and organics
   c) Fraser River discharge (seasonal – freshet (time of IONA sampling), variability year-to-year, proportion of total sediment loading to area)
   d) Climate changes (El Nino/LaNina – see OCSD 2000, etc.), changes in sea-surface temperature and primary productivity of the area can affect benthos – see Lee and Pritchard 1997)
   e) Other contaminant discharges
   f) Unusual, unpredictable recruitment of species which can affect substrate quality or distribution of important community components (this can usually only be determined from long-term monitoring programs (c.f. Stull et al. 1986a,b)
      i. Native species
      ii. Exotic species

7. *How do the indicators selected interact?*

   a) Levels of one factor that co-vary with others
   b) Synergistic effects between suites of indicators

8. *How should these indicators be changing over time?*

   a) To show improvement
   b) To show degradation

9. *What are the spatial constraints to these changes?*

   a) How close to the outfall should monitoring take place
   b) What levels of indicators are acceptable at varying distances from the outfall

4.3 DEVELOPMENT OF WARNINGS AND TRIGGERS FOR BENTHOS

4.3.1 Introduction

The development of a framework for benthic indicators, warnings and triggers for the Iona and Lions Gate receiving environments requires a series of tasks:

1. Determine what is known about wastewater effluent effects on benthic marine habitats and how other jurisdictions regulate these receiving environments
   a. Review of indicators and triggers used for monitoring and regulation of other marine discharges internationally (see also Appendix C)
   b. Review of types of environmental effects that can occur in habitats receiving wastewater discharge deposition (see also Appendix D)
2. Detailed analysis of the spatial and temporal effects based on the revised monitoring program at Iona and Lions Gate.
   a. Assessment of ecological significance of observed biotic effects in the Iona receiving environment now or in the future (Appendix D)
   b. Comparative analysis of results from the Iona 2003 monitoring data with previous monitoring years (EVS 2004)
3. Design framework for derivation of warnings and triggers for Iona and Lions Gate

Process #1 has been completed and is attached to this document as Appendix C (Burd 2002a). Major conclusions based on this review are included below (section 4.3.2). Process #2 has been accomplished by an up-to-date review and comparison of all monitoring data from Iona in the annual reports (EVS 2001, 2003, Bailey et al. 2003) and in several special reports and presentations to GVRD (Burd 2000, Burd, 2003a) and is summarized in section 4.3.2. Section 4.3.3.2 includes a summary of biotic and related geochemical effects measured in the preliminary monitoring program for Lions Gate. Finally, the ecological significance of observed biotic effects in the Iona receiving environment has been addressed in Burd (2003a – see Appendix D) and summarized in section 4.3.3 below.

4.3.2 What is known about Benthic Biotic Responses to Wastewater?

Review of indicators and triggers used in other jurisdictions (Burd 2002a – Appendix C)

Existing benthic guidelines and indicators used in other jurisdictions (primarily North America) were assessed as to their respective success and applicability to the particular receiving water environments of the GVRD marine discharges.

Most of the environmental research and monitoring literature is focused on the issue of input and effects of “contaminants”, primarily chemical. Unfortunately, there is a lack of clear and convincing evidence related to the in-situ effects of contaminants on biota in the receiving environment. Cause and effect relationships are generally based on spiked toxicity tests for specific biota (which may or may not be relevant to the habitat in question), or on whole sediment tests which do not isolate causative factors and are often confounded by geochemical effects related to enrichment.

Although the importance of enrichment effects are recognized, and there is a vast literature going back to the early 1900’s pertaining to enrichment effects on biota and habitats, the focus of jurisdictions in North America for developing receiving environment guidelines, triggers and indicators has been on chemical contaminants. There are geochemical effluent guidelines (BOD in effluents), but the coupling of these with habitat effects is largely theoretical. The exception to this is Washington State, which uses sediment TOC related to percent fines, and the fish-farming regulatory framework for the east and west coasts of Canada, which are experimenting with sediment free sulphide guidelines for fish waste deposition. This is problematic with respect to wastewater discharges, since North American experience suggests that organic enrichment effects are the primary causal factors affecting receiving environments.

Ideally, useable receiving environment indicators should address the following questions:

1. Are contaminants getting into the system?
2. Are contaminants bio-available?
3. Is there a measurable response?
4. Are the contaminants causing this response?
5. Are the responses of ecological importance now or in the future?
6. How do we respond to ecologically important effects?

The first four questions are inherent in Environment Canada’s national Environmental Effects Monitoring Programs (EEM) for Pulp and Paper and Metal Mining. Most of the regulatory framework and guidance that has been developed has been oriented towards answering questions 1-4. The resolution of these questions is amenable to rigorous scientific monitoring and research for receiving environments. However, questions 5 and 6 must be addressed by regulatory agencies if triggers and warnings are to be used in a management framework for discharges. Questions 5 and 6 are only partially addressable by science, and partially by societal standards and ethics.

For the triggers and warnings framework for a wastewater discharge, the pertinent questions may be more clearly stated as:

Can the zone of influence of the discharge be measured and tracked over space and time?

1. Are there biotic effects within the zone of influence?
2. Can these biotic effects be confidently associated with the discharge?
3. What factor(s) cause these biotic effects?
4. Are the effects of ecological importance now or in the future?
5. How do we respond to ecologically important effects?

Questions 1 - 3 are relatively straightforward to answer, and have been the focus of the annual Iona monitoring program. The revised monitoring program has been very successful at showing the magnitude, extent and temporal stability of benthic and sediment contaminant distributions related to the Iona discharge. This will be described below. However, questions 4 - 6 are not straightforward. The factors causing any biotic effects may or may not be contaminant related.

It is often not clear what the purpose of sediment quality guidelines is. Most commonly, the purpose of setting any sediment guidelines is to "protect the health of the ecosystem". If this goal is to have a realistic function, then the parameters of a "healthy" or "unhealthy" ecosystem must be defined. A glaring omission in virtually all regulatory and criteria-based guidelines for environmental management is the analysis of what constitutes an "ecologically significant effect". Ecologists view ecosystem "health" in relation to the overall spatial and temporal functionality and stability of the major biotic components. This is difficult to measure, and endpoints are far from clear-cut. In addition to preventing accumulation of toxic chemicals up the food chain, ecosystem "health" implies that a stable habitat and food supply must be maintained for the higher trophic levels. Statistical significance is generally equated to ecological significance, but reflects only the mathematical properties of the data and sampling program, rather than the biological properties of the ecosystem.

There are few ecosystem-based (receiving environment) biotic guidelines for regulatory purposes. The U.S. E.P.A. has recommended the used of biotic criteria in water quality monitoring, and this has been attempted in some states in the U.S.A (for review see Appendix C). Lowe and Thompson (1997) discuss the potential advantages and problems associated with using different biotic indicators for discharges in the San Francisco Bay area (Lowe and Thompson 1997). Washington State has developed a set of Apparent Effects Thresholds (AET) for sediment contaminants based partly on benthic infaunal community effects, which are used to help regulate their wastewater discharges. There are some biotic guidelines for determining acceptable levels of effects in marine environments, although these are somewhat arbitrary. CRD developed a draft triggers document (2000) for their marine discharges, in cooperation with MELP and their Marine Monitoring Advisory Committee. The document includes three biotic "triggers" (Species richness, Swartz Dominance Index and enhanced polychaete abundance). It is instructive to note that CRD's conclusions with respect to the use of CCME guidelines for contaminants or Washington State AET's (excerpted from draft Trigger document – CRD 1999) include:

- *CCME guidelines have only about 50% reliability in predicting adverse effects observed in biological tests conducted in the discharge area;*

- *Washington State AET's are much more reliable in predicting effects, but do not enjoy the same degree of agency acceptance as the CCME guidelines in B.C.;*

- *Both sets of guidelines are based largely on bioassay data, while adverse effects on the benthic community observed near the outfalls are not well-correlated with bioassay results;*

- *Changes in the benthic communities near the outfalls appear to be more highly correlated with conventional (organic) loading than with toxicants; and,*

- *Neither set of existing guidelines includes numeric levels for conventional substances such as TOC that may be important near the outfall. Traditional bioassays are designed to minimize the impacts of conventional parameters during the test; therefore, approaches that rely largely on bioassay data may not be very accurate in predicting the potential for effects near the outfalls.*

Toxicologists define ecosystem health as a system in which a reasonable percentage of toxicity is possible based on controlled testing of surrogate organisms. However, this does not address the "true" toxicity experienced by the biota in that system, or variation in toxicity in each species and life stage. Ecologists view the issue of ecosystem health somewhat differently. They are concerned with the overall functionality and stability of the ecosystem. In addition to preventing accumulation of toxic chemicals up the food chain, this means that a stable and usable habitat and food supply must be maintained for the higher trophic levels. Increasingly impacted communities are characterized by progressively greater variability in abundance, biomass and biotic composition, as well as habitat conditions. This temporal variability is a destabilizing factor in ecosystems. The spatial extent of the effects, specific location of effects relative to sensitive and important species, and temporal recovery potential are important considerations in determining ecosystem health or relevance of impact. Two general aspects of ecological importance are of concern, the first of which is:

> ***A: What is the balance or stability in biotic composition and functioning of components of the ecosystem, or geographic locations of specific concern?***

To address this issue, many jurisdictions utilize a tiered approach to monitoring and evaluation of effects.

Tier 1: Application of universal, often national or regional guidelines based on some critical mass of laboratory-based and empirical research. This approach requires no background information or understanding about the habitat in question. The review describes the historical derivation of sediment quality guidelines based on toxicity testing and equilibrium partitioning, which has been fraught with problems. More recently, measures of bio-availability and tissue level response of organisms to toxicants encompasses a massive effort which is still on-going. However, existing national or regional sediment guidelines are generally viewed as first tier indicators, which may flag potential situations of concern and trigger further monitoring. If there is a "hit", more detailed work is required. However, if the guidelines are not exceeded, the decision is more difficult. It must be assumed that either there are no receiving environment effects, or a 2nd tier of monitoring must be done to determine if there are biotic effects.

Tier 2: Because the aforementioned "ecological" issues are tricky to assess, most regulatory agencies define ecosystem health as some proportional deviation from "normal" or "reference" conditions. The "Reference" approach implies that the habitat and/or biota in question have been examined. This may be required after a 1st tier guideline(s) has been exceeded. However, the result of finding a change from reference condition without any "hits" related to guidelines implies that something other than the “regulated” or guideline parameters is having an impact on the habitat and biota. To set standards, the temporal and spatial scale of variability that can be expected in natural “present-day” conditions must be determined. This is a complex and difficult task that must be accomplished in proximity to the impact of concern. The next step is to determine on some rational basis, what deviation from “reference” is acceptable, and over what spatial and temporal scale. This is usually done statistically, but may include locally regulated initial dilution zones around the effluent source.

Tier 3: A Toxicity Identification Evaluation (TIE) is required if a negative change or impact in discovered in Tier 2, to attempt to determine what is causing the biotic impact. The literature on how to do this is extensive. If this approach is not suitable, an empirical “weight of evidence” assessment of the causative factor(s) may be required.

The second aspect of ecological concern, which does not lend itself well to focused receiving environment monitoring programs, is:

> ***B: What are the ramifications of an impact up the food chain; effects on higher trophic levels up to humans (food, health and recreation)?***

There may be impacts occurring outside the immediate vicinity of the discharge, which we cannot see, trace or measure. This problem has become more prevalent in recent years, as concern over known deleterious substances (such as POPs) grows. Determining these higher trophic level effects is difficult, since they may be slow to develop and difficult to trace to their origins. Therefore, they are not useful for local jurisdictions because they cannot be tracked, predicted or used as management tools due to measurement uncertainties and time scale. However, they cannot be ignored either. Such aspects of ecological significance are best addressed through ambient monitoring programs and the careful tracking of source tracers.

Therefore, for management in real time, (A) above is the only practical way of developing triggers and guidelines for specific discharges. The indicators may be scientifically based, but the ecological importance is partially scientific and partially passed on societal values and best professional judgement.

Biotic and Related Organic Geochemical Effects at wastewater outfalls (Appendix D)

There are three basic types of disturbance, which can affect the distribution of macrofauna either directly or by shifts in overall biotic interactions. These include:

a) physical disruption
b) toxic contamination
c) organic enrichment

The effects of these three types of impact on marine macrofauna are discussed with respect to a variety of anthropogenic activities in addition to wastewater discharges and relevance to the Iona discharge. One method of putting the ecological significance of the Iona discharge effects into perspective is to examine the types and extent of effects found at other wastewater discharges, particularly those on the west coast of North America, where species associations and habitat types are similar. Monitoring of benthic sediments and communities near wastewater outfalls from Puget Sound and Washington, and the entire coast of California has been extensive. Some information is also available from the New York Bight and northern Europe where extensive monitoring programs have been carried out. However, in Europe and the eastern seaboard, sewage sludge dumping is a more common form of disposal than discharging through outfalls. Extensive monitoring data is available during and after cessation of sewage sludge dumping in the New York Bight (Reid et al. 1991; Studholme et al. 1995).

The patterns of faunal change related to effluent discharge are strikingly similar for almost every other wastewater discharge on the west coast of North America. In general, the organically enriched sediments tend to have high abundance of a few tolerant opportunists, primarily polychaetes, which tend to be tolerant of the most extreme conditions, followed by bivalves, which seem to be tolerant of somewhat enriched, and even moderately hypoxic sediments. However, the echinoderms and microcrustacea (amphipods) are the first species to show effects from wastewater exposure.

Sediment geochemistry near discharges varies considerably depending on the substrate type, depth, sediment transport and current regime in the receiving environment. In sediments with relatively low inorganic inputs from riverine runoff, and low transport, total organic carbon has been used to assess the additional input of organic nutrients to native sediments. Additionally, the monitoring program for the major southern California discharges (Orange County Sanitation District – OCSD 1996, 2000, 2002) has monitored acid volatile sulphide (AVS) as a means of examining geochemical changes related to redox in sediments near outfalls. AVS has also been measured as part of the CRD Macaulay Point receiving environment monitoring program off Victoria, B.C. In both jurisdictions, AVS has been useful for tracking sediment organic enrichment.

Organic particulates from discharges tend to produce a declining gradient of sediment geochemical changes, which reflects the current and/or sediment transport regime of the area. Often, the major deposition is not in the immediate vicinity of the outfall, or at the depth of maximum discharge. Nevertheless, the ultimate fate or footprint of the organic deposition can be readily tracked by changes in sediment geochemistry. As organic loading increases, bacterial decomposition increases, as does bio-geochemical oxygen demand. When the organic loading exceeds the capacity of sediments to break it down (based on oxygen delivery to the surface and deeper sediments), oxygen levels decline and related chemosynthetic bacterial production of hydrogen sulphide increases. The redox layer in the sediments may rise up to near-subsurface levels, and associated mobilization and release of methane, ammonia and carbon dioxide may occur. Various invertebrate species respond with behavioural and physiological adaptations to these conditions. The least successful species decline first, leaving fewer and fewer highly tolerant organisms living at shallower depths in or on the sediments. Larger bioturbators are among the first species to decline, reducing the delivery of oxygen to deeper layers of the sediments, and thus reducing habitat heterogeneity, surface area for bacterial production and organic breakdown, trophic complexity and distribution of biomass, and thus further reducing the assimilative capacity of sediments for organic deposition. The end, or extreme result is entirely azoic sediments with complete defaunation of macro-invertebrates.

4.3.3 Current status of benthic marine receiving environments

Iona Monitoring Program

The monitoring program for receiving environment effects in the Iona discharge region was revised based on a 10-year review of the historical program in 1999 (2WE Consulting 1999). The revised program has been completed for 2000 to 2002 (EVS Consultants 2001; 2003; Bailey et al. 2003), with the field portion of the 2003 program complete. The historical monitoring data was re-examined along with results from the first year of the revised monitoring program (Burd 2000).

In order to estimate how the community varies over time it is necessary to have time-series data on a scale adequate to determine natural variability. In total, there are benthic community data from the Iona area pre-outfall (June and July 1983), March 1990 (data not considered acceptable because of preservation and field sampling problems) and March 1991 and 1995. The pre-outfall data from 1983 were sampled using a smaller sieve size than in subsequent years (0.6 mm versus 1 mm). Taxonomic precision was not rigorously quality controlled during these years, and no reference collections or verifications are available. However, field and laboratory methods were relatively consistent over the historical monitoring period. The sampling grids used from 1990 to 1995 were not conducive to determining the maximum potential effects from the discharge, and were seriously depth confounded (2WE 1999; Burd 2000). Nevertheless, some stations sampled in 1990 and 1995 were at similar depths to the revised monitoring program (see below), and were useful for comparisons of temporal trends (see Burd 2000).

The benthic infaunal effects from the Iona 2000 monitoring programs were specifically addressed in a statistically rigorous way in Burd (2000), and to a lesser degree in EVS (2001). Field and laboratory methods were consistent with the historical monitoring program. A few improvements were added for quality control, including separation of adult and non-adult counts, and biomass measurements for major taxonomic groups.

The sampling design was modified to better assess the maximum exposure potential in macrofauna around the outfall. The best evidence of the distribution of Iona discharge effects on sediments prior to 2000 was the study of sediment silver by Gordon (1997). According to this study, sediment effects might be expected along the 90 m depth contour in a gradient to the north, and less so to the south of the outfall. Results of the Hodgins and Hodgins (2000a) report on sediment deposition of total suspended solids suggest that initial deposition is maximal upslope of the 90 m contour. Therefore, significant down-slope sediment transport is occurring over time.

A compromise to identify the maximum exposure zone in terms of infaunal communities resulted in choosing the 80 m depth contour for sampling, thus eliminating the depth confounding problem. The revised sampling grid along the 80 m depth contour for 2000 onward, is shown in Figure 7 in Chapter 3.

Setting up a gradient design in 2000 by which hypotheses about the relationship between physical or chemical sediment factors and biotic factors could be tested directly, circumvented the lack of "un-confounded" reference stations. The design also included sufficient stations/replicates to do near- and far-field comparisons of biotic factors with adequate statistical power, using simple 95% confidence intervals as criteria (based on Environment Canada EEM protocols for Pulp and Paper and Metal Mining: URL: http://www.on.ec.gc.ca/eem/pulppape-e.html). The far-field stations could be used to start building a reference database to define criteria.

A comparison of biotic results from the 2000 and 2001 monitoring programs is included in EVS (2002). The 2000 monitoring program was repeated in 2001 with one major difference. Field sample processing and taxonomic identification were done by a different consultant in the two years, with a shift in quality control resulting in an increase in species richness by 30-100%, an increase in abundance up to 100% and some increase in biomass in 2001. Some quality control improvements included the development of a properly and completely verified taxonomic reference collection, and the use of species-specific wet weights to allow a biomass conversion of abundance data. Thus, two methods of biomass measurement were used. Totals calculated using both methods were compared with little notable disagreement in results (2002).

The monitoring program for 2002 and 2003 were conducted in the same way as in 2001. Quality control and procedures were all the same, except that total biomass for major taxonomic groups was not included. Results are included in EVS (2003, 2004).

General Characteristics of the Iona Benthic Biota and Sediment Geochemistry

The biotic community in the Iona receiving environment is described in detail in Burd (2000, 2003a) and EVS (2001, 2003, 2004, Bailey et al. 2003). The specific composition of the community varies in identified zones related to the effects of the discharge (see Appendix D). A description of the faunal character of each of these zones is noted. Due to a well designed and quality controlled monitoring program, determining whether or not biotic effects are occurring in the Iona receiving environment and whether or not these effects are related to the discharge, has been relatively straightforward. The 2000 monitoring program showed clear effects unequivocally related to the discharge. It also illustrated the presence of important confounding factors, and a different, unrelated source of faunal impacts in the area. The 2001 and 2002 programs showed the temporal variability in these effects over the three year period.

Some general characteristics of the biota were universal to the sampling area. All stations were characterized by a dominance of small bivalves, followed by polychaetes, with varying numbers of echinoderms and crustaceans. The community is typical for a sandy silt habitat in relatively shallow subtidal coastal areas of B.C. (80 m depth) with moderate organic input.

The echinoderms and crustaceans showed the most sensitivity to effluent exposure, based primarily on changes in sediment geochemistry. Both groups declined precipitously in the most exposed zone. However, ophiuroids showed a marked opportunistic enhancement in the surrounding areas, which had organic enrichment with only minor sediment geochemical changes. More subtle but important differences were noted for the "age" structure of bivalves;

immature forms tended to be more sensitive to effluent exposure than adult forms. A relatively minor enhancement of some typical organic enrichment polychaetes was evident in the near-field (most exposed) zone.

The sediment geochemistry is complex in the IONA receiving environment. That total organic carbon (TOC) was not a useful indicator of sediment enrichment effects was clear even in the historical monitoring program. TOC levels are invariably low and change very little in the discharge deposition zone (Figure 12). This is probably due to the relatively high contribution of inorganic particulate material to sediments in this region from discharge related to the south arm of the Fraser River. This river discharge tends to swamp the organic signature.

However, sediment AVS values do show a zone of sediment change related to the discharge (Figure 13). This change involves an increase in acid volatile sulphide, which are a result of the production of hydrogen sulphide from bacteria living at the oxic/anoxic boundary in sediments. The elevated levels of AVS in near-surface sediments suggest considerable bacterial activity and reduction of sediment oxygen levels near the sediment/water interface. This is a direct result of organic enrichment from wastewater particulates.

Mean AVS levels have remained surprisingly constant from 1994 to 2002 (Burd 2003a – Appendix D), suggesting that the mean or long-term sediment geochemistry changes related to the discharge have also remained relatively constant over that period. However, the monitoring program does not provide information related to short-term perturbations around the mean value. Certainly, field samples suggest some degree of spatial patchiness, both vertically and horizontally, in sediments. This short-term variability may have some biological impact.

The mean 4-nonylphenol levels for the Iona sampling gradient are shown in Figure 15. CCME (2002) has developed interim marine sediment quality guidelines of 1 mg/g for 1% TOC toxic equivalency units (TEU). This metabolic byproduct is an aromatic alcohol, and is included to indicate that it follows a pattern of distribution similar to AVS, and is considered an excellent indicator of sediment exposure to the Iona discharge (Chapman and Paine 2000, Bailey et al. 2003).

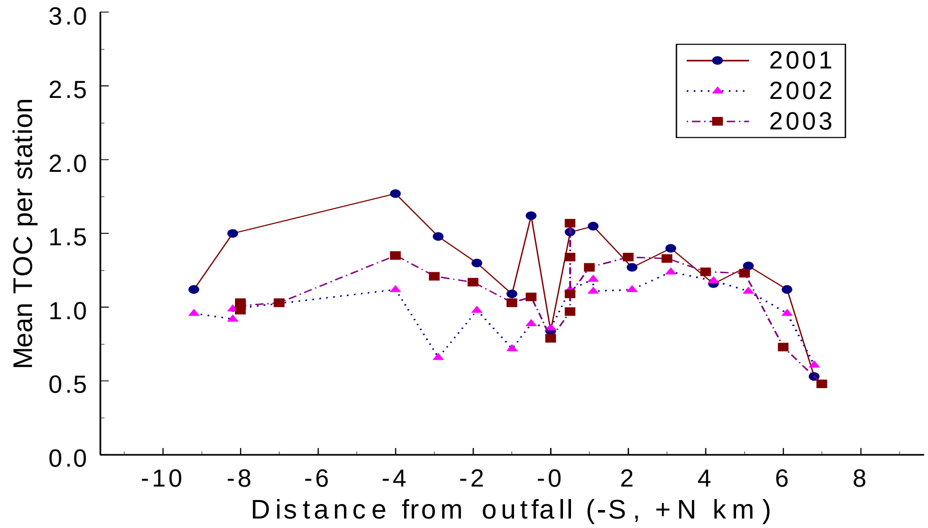


Figure 12. Mean total organic carbon (TOC % dry wt) over time related to the Iona discharge

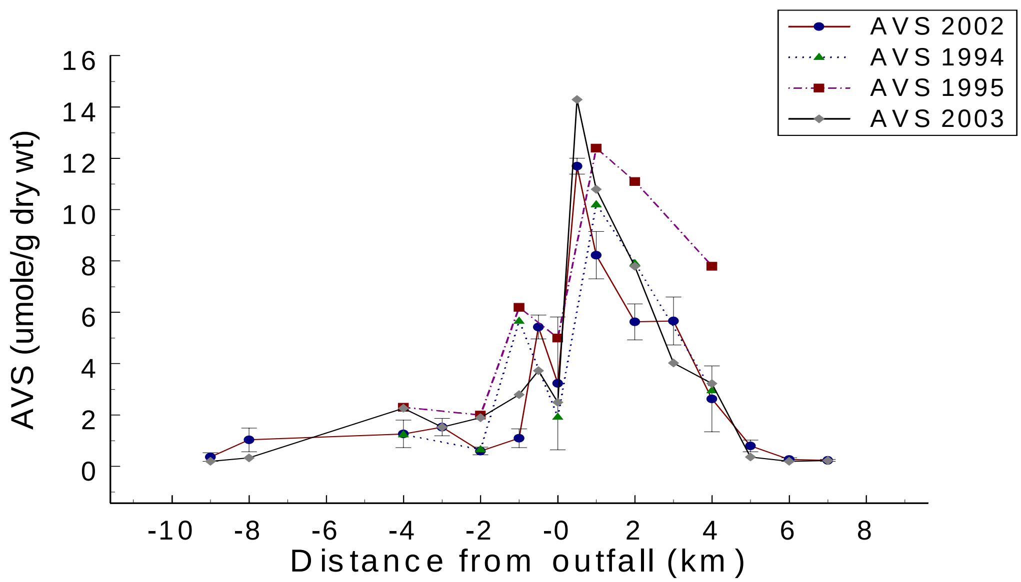


Figure 13. Mean AVS over time related to the Iona discharge

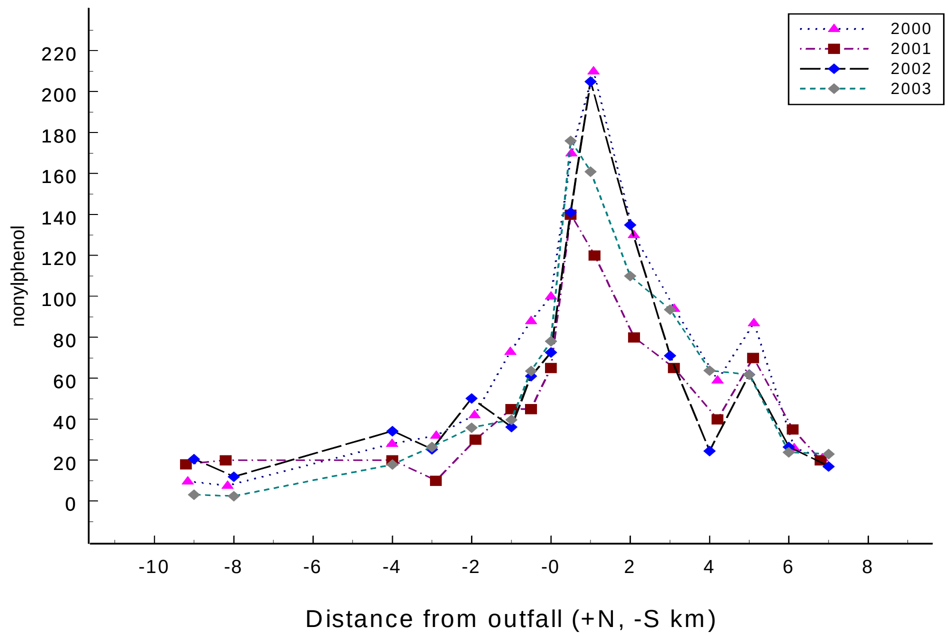


Figure 14. Mean 4-nonylphenol over time related to the Iona discharge

Note that the maximum value shown is about 30% CCME Interim Guidelines for TEU for marine sediments at TOC = 1%

Derivation of Reference Ranges and Effect Zones at Iona

Figure 15 shows the zones of impact as derived statistically from monitoring data for 2000 to 2003. Reference ranges for "background" conditions for the area are estimated using the method developed in Burd (2000, 2003a – Appendix D), followed by a statistical assessment of the magnitude and character of deviation in "exposed" conditions from these reference ranges (see Burd 2003a – Appendix D). The stations are sorted into "most impacted", "less impacted", "background (or reference)" and "confounded" for the purposes of long-term assessment of changes in impact. It was concluded that over the period of 2000-2002, benthic conditions appear to have remained stable in the Iona receiving environment. Limited unconfounded data from 1991 and 1995 suggest that this stability has been inherent in the area since shortly after the commissioning of the deep-sea outfall (Burd 2000, 2WE 1999). There were no "gross" impact areas identified; serious defaunation and declines in species richness were not noted for any station.

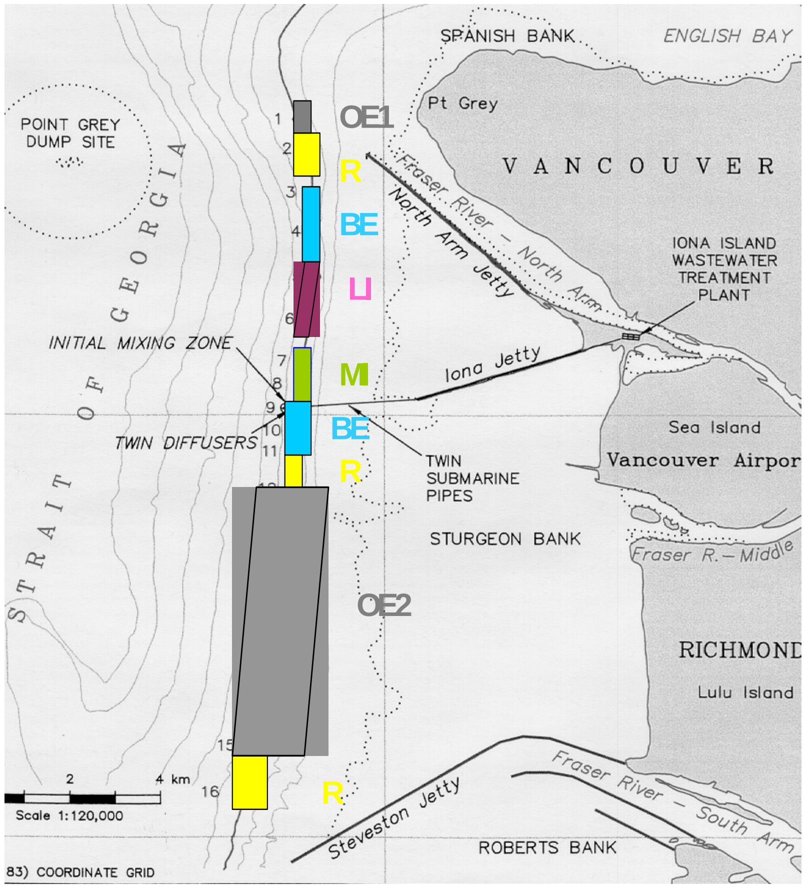


Figure 15. Derived "effect" zones for the Iona 80 m depth monitoring grid

OE1 = outside effect zone 1, OE2 = outside effect zone 2, R = reference zone, BE = biotically enriched zone, LI = low impoverishment zone, MI = moderate impoverishment zone

Moderately impacted: consistent but moderate declines in abundance, species richness, biomass and the most abundant and relatively tolerant bivalve, Axinopsida serricata; virtual elimination of echinoderms, crustaceans, modest enrichment of opportunistic polychaetes and dominance of a few taxa (decreased Swartz Dominance Index - SDI); highest AVS, sterol (ie coprostanol) and nonylphenol indicator (wastewater deposition) values. Conditions suggest reduced oxygen in sediments but not complete anoxia in near-surface. This effect zone seems to fluctuate between 0.5 to 1 km north of the outfall. Faunal composition tends to be significantly distinct in this area with or without the dominant bivalve Axinopsida serricata (EVS 2003, Bailey et al. 2003). Some biotic changes in this category may be related to chemical contaminants, but are too subtle to distinguish in of the current monitoring program and seem unlikely based on the limited knowledge of contaminant effects in habitats

Less impacted: moderate declines in species richness and SDI, with abundance and biomass variable or enriched (bivalves and polychaetes); virtual elimination of echinoderms, crustaceans; elevated AVS and sterol indicators. Conditions suggest moderate or mild hypoxia in near-surface sediments. This area seems to be relatively stable, surrounding the most impacted zone from 1-3 km N and 0- 0.5 km S of the outfall. Faunal composition is consistently significantly distinct from both the enriched zone and background zones (see categories 3 and 4 below) when the dominant and relatively tolerant bivalve *Axinopsida serricata* adults are removed from analyses (EVS 2003, Bailey et al. 2003). However, intermediate and juvenile *A. serricata* are reduced in abundance in this zone. Shell staining on *A. serricata* is reduced in this zone.

Enriched**:** no declines in species richness, abundance, juvenile recruitment or biomass; enrichment of some taxa such as ophiuroids; depression of a few species particularly sensitive to surface disturbance; normal or enriched echinoderm abundance, background AVS and sterol indicator levels. This zone (mid-field) is found between 4-5 km N and 0.5-1 km S of the outfall. There is no indication of sediment hypoxia, although some sediment organic enrichment is suggested by biotic enrichments. This area shows does not show statistically significant differences in faunal composition from far-field stations (reference condition).

Background**:** The far-field stations 2,12,15,16 are considered to represent background conditions in the Iona receiving environment. There are significant differences in faunal composition from the northern-most to the southernmost of these stations, which is probably related to the S to N gradient of input to sediments from the south arm of the Fraser River. However, in total, the faunal complement of aforementioned stations is considered to encompass the natural range in biotic composition for this region for sandy-silt to silty-sand substrates in the 80 m depth region. The faunal composition of this far-field grouping is significantly distinct from that of the impoverished zones (MI,LI), but not the enriched zone (BE). The enriched zone extends from 2 km S to 9 km S and 6+ km N of the outfall, and.has a faunal composition intermediate between the N and S far-field stations.

Confounded**:** Stations 13 and 14 (within OE2) show faunal impoverishments in species richness, abundance and sometimes biomass, which are not related to organic enrichment (normal SDI) and show no opportunism except in a few large, deep-burrowing species (Burd 2000; EVS 2003, Bailey et al. 2003). Near-surface species and those sensitive to surface disruption are reduced. Conditions suggest a physical disturbance variable in extent and magnitude, sometimes evident in 1 of the replicate samples for the surrounding stations 12 and 15. This zone is in the middle of the southern far-field region. Station 1 shows erratic and patchy disturbance. Sediment chemistry suggests periodic dumping of dredged material in much sandier substrate than the other Iona stations. Therefore, although no organic enrichment is suggested (consistently high SDI), faunal composition at station 1 tends to be significantly distinct from all other stations, probably related to intermittent disruption and different substrate preferences of major taxa relative to the other far-field stations. This station is 7 km N of the outfall and en route to the Point Grey Dumpsite.

Reference ranges for Iona biotic and sediment exposure indicators (2001-2003) are in Table 22.

Table 22. 95% reference ranges for adult plus intermediate biotic factors for 2001-2003 at Iona

(using the far-field stations 2, 12, 15, 16 as reference (see Appendix D for full descriptions of indicators)

	adults/00		**adults/01***		**adults/02***		**adults/03***		**Adults**	**2001-2003**
95% based on cum frequency	Lower Ref	Upper Ref	Lower Ref	Upper Ref	Lower Ref	Upper Ref	Lower Ref	Upper Ref	Lower Ref	Upper Ref
	Range	Range	Range	Range	Range	Range	Range	Range	Range	Range
Dissimilarity to mean ref		;46%		38%		41%		39%		46%
Polychaete abundance	37	166	188	570	197	381	80		130	740
Bivalve abundance	87	256	458		576	1341	390		400	
Echinoderm abundance	16	35	13		14	60	21		19	
Arthropod abundance	15		14	152	12	115	7		7	
Percent bivalves	35.40%		37.50%		61.00%		51%		38%	
Percent polychaetes	12.30%		16.30%		16.30%		10%		12%	
Percent crustaceans	6.90%		1.80%		1.20%		<1%		0.70%	
Percent echinoderms	6.20%		1.60%		1%		1.00%		1.50%	
total richness	33		67		70		61		66	
total abundance	263	708	899	1791	1039	1789	932		927	
Adult abundance	187	471	777		838	1705	824		784	
Adult richness	25		67		70	78	61		62	
Percent juveniles	34%	55%	7.6%(37%**)		5%		6.50%			
SDI (CRD, PSRP)	6		6		5		5		5	
Biomass (minus holothurians)	11.3	29	14.5		24.4	71.8	13		17.5	
Heterophoxus oculatus/affinis	8	23	2	22	3	35	1		2	
Capitella capitata complex	0	0	0	4	0	10		5		9
%C. capitata		0		<1		1		0.50%		1%
Axinopsida serricata	51	156					351		365	
A.serricata imm			180		195		131		159	
%A.serricata imm			41%		39%		31%		35.00%	
Amphiodia urtica	14	34	7		6		8		12	
Macoma carlottensis	7		93		19	323	42		18	
Heteromastus filobranchus	0	0	0	3	0	6		9		12
%H. filobranchus								0.70%		1%
Cossura spp.	0	3	0	16	0	10		8		16
*%A.serricata adults 0/1 cat stain**	n/a		6.70%		6.00%		3.70%		6.50%	
Sediment fecal colliforms.	43		530**		70		150		150	
AVS (umol/g dry wt)	n/a		n/a		1.5		2.8		2.4	
4-nonylphenol (ug/g)	42		35		50		36		42	

*** For description see section 4.1**

Ecological Significance of Benthic Biotic Effects at Iona (Appendix D)

The ecological significance report (Appendix D) synthesizes the results of the historical and recent Iona monitoring data and includes a review of recent literature (focusing on 1985 onward) pertaining to ecological implications of wastewater disposal for marine benthic infauna. Appendix D discusses the ecological implications of the measured effects to the health and stability of the benthic community, and potential effects on other trophic levels utilizing the benthos. This report does not address the significance of potential tissue contamination or direct effects from the effluent on epifauna, bottom fish or higher trophic levels in the water column. Pertinent questions addressed in this report include:

1. What are sustainable biotic levels (abundance, biomass, species richness, balance of taxonomic and trophic groups) for the benthic infaunal communities in the receiving environment of the Iona discharge?
2. What are the likely causes of specific faunal declines in the receiving environment of the Iona discharge?
3. What are the likely outcomes to the overall community and bottom fish assemblages of the faunal effects from the Iona discharge?

Ecologists view ecosystem “health” in relation to the overall spatial and temporal functionality and stability of the major biotic components. In addition to preventing accumulation of toxic chemicals up the food chain, ecosystem “health” implies that a stable habitat and food supply must be maintained for the higher trophic levels. Increasingly impacted communities are characterized by progressively greater variability in abundance, biomass and biotic composition, as well as habitat conditions. This temporal variability can be a destabilizing factor in ecosystems, making it almost impossible to predict dramatic fluctuations in biotic factors. The ecological importance of the faunal declines noted in organic enrichment situations is related to a series of issues discussed below.

The report concludes that sediment geochemistry changes are primarily responsible for benthic invertebrate effects around Iona. Small eutrophic patches in otherwise well-oxygenated basins are of minor concern unless they directly impact a rare or important biotic resource (fish spawning habitat, geoduck beds, etc.). However, the spatially cumulative effect of many such patches in limited regions could be considerable. Diaz and Rosenberg (1995) concluded that the spread of hypoxia in coastal enclosed and stratified waters is of greater ecological importance and has spread much more drastically in a shorter period than any other anthropogenic impact in marine waters. Obviously, the spatial and temporal duration and extremity of such patches within the greater habitat must be judged with respect to their ecological significance.

The spatial extent of the effects, specific location of effects relative to sensitive and important species and temporal recovery potential are important considerations in determining ecosystem health and/or relevance of impact. At Iona, the sediment effects are estimated to be maximal in the 60-80 m depth range to the north of the outfall. This entire region is utilized by bottom trawlers, particularly for shrimp.

In soft substrates, bioturbation has profound effects on the depth distribution of organic material and thus bacterial production in sediments along with complexity of sediment structure, oxygen diffusion and related geochemisty, and mobilization of contaminants from beneath the sediment surface. The larger (and deeper) the bioturbator, the more it tends to stimulate mineralization by oxygen delivery to deeper sediments, whereas small bioturbators such as *Capitella capitata complex* stimulate bacterial activity. The larger, long-lived bio-turbators tend to be sensitive to hypoxia (especially echinoderms), and may take much longer to recover after any type of disruption (c.f. Burd et al. 2000). The long-lived organisms must have sediment conditions that remain within tolerable limits at all times. If these limits are exceeded, they may disappear for at least a year, and sometimes much longer if cues for recruitment are dependant on the presence of adults in the habitat. Therefore, bioturbation increases rates of both nitrification and denitrification (Heilskov and Homer 2001, and see references in Rosenberg 2001). Thus, the continued presence and health of the bioturbators in sediments is vital for preventing build-up of organic material.

On the converse side of this argument, the presence of an active and relatively deep bioturbation layer serves to keep sediment contaminants mobilized and available to surface organisms. Eventually, sediment contaminants become unavailable to biota as natural sedimentation buries contaminated areas.

The obvious decline in ophiuroids near the Iona discharge with increasing toxicity of sediments (probably due to low oxygen and high hydrogen sulphide) north of the outfall suggests a distinct and measurable loss to bio-diversity and standing stock. However, the ophiuroids were obviously attracted to, and initially enriched by the organic output from the discharge and did not seem to be a major component of the assemblage in the immediate area prior to deep-sea discharge. Therefore, the discharge serves to both reduce and enhance ophiuroid abundance in the Iona region. Overall, assessing the balance of these two effects is difficult.

The decline in amphipods and other crustaceans near the Iona discharge is perhaps more symptomatic and of concern with respect to the overall trophic food chain of the area. Non-specific feeders such as Dover sole are not at a disadvantage because they simply switch their prey items when the benthic community changes. Shrimp also seem to take advantage of organic pollution and proliferate in outfall areas. Certainly, there seems to have been an increase in the shrimp fishery in the Iona discharge area since the commissioning of the deep-sea outfall. However, benthic crustacean feeders would be negatively affected around outfalls. In general, Spies (1984) concluded that fish diversity declines near outfalls, but overall biomass increases. Effects are most notable in the more sessile species which do not range widely to feed, but are dampened in the higher trophic, more mobile species.

What is perhaps most critical to foraging fish in the Iona discharge area is the ready accessibility of food on the surface of the sediments. This would be most important to the juvenile or smaller fish, which require small prey. Both ophiuroids (mainly arms) and amphipods are important to the benthic juvenile fish community because they are on or above the sediment surface and therefore readily accessible prey of the right size. The ophiuroids and crustaceans are replaced in abundance by small and medium-sized bivalves and a few small polychaetes. Many of these deposit feeders are burrowers, which means that they are less accessible to surface foragers. In general, the conditions which seem to exist north of the Iona outfall would be less hospitable to the epifaunal or suspension-feeding organisms which provide an important and ready food resource, particularly for juvenile fish.

Of considerable additional concern is the bio-accumulation or bio-magnification of toxic contaminants up the food chain. This topic is outside the scope of the report, since the benthos monitoring program at Iona is not designed to address this issue. It is a complex topic, which tends to have region-wide imperatives and ramifications, and is best addressed within regional initiatives such as the Georgia Basin Action Plan (URL:

http://www.pyr.ec.gc.ca/GeorgiaBasin/gbeiIndex_e.htm).

There are a series important issues in this topic, including bio-availability of contaminants, trophic accumulation potential of different species or predator and prey, persistence of toxic chemicals with trophic transfer, metabolic conversion of non-toxic chemicals to more toxic forms, modes of effect of different toxicants at the toxic and sub-lethal levels, behavioural avoidance mechanisms, source identification and quantitative tracking of substances through the food chain.

Based on a careful examination of the faunal communities and habitat data present for Iona, on a wealth of (mostly unpublished) monitoring data and research from other jurisdictions and discussions with invertebrate specialists, the ecological significance of effects of the Iona discharge on benthic infauna can be simplistically summarized as follows:

1. *The spatial extent of biotic effects appears to be within 3 km N and 0.5 km S of the outfall, with the most pronounced effects within 1 km N. The patterns of change in the affected area are typical for other marine habitats, which have organic enrichment due to natural or anthropogenic input.*
2. *Natural conditions (i.e., Fraser River discharge) seem to prevent organic buildup and progressive degradation of sediments. Thus biotic and sediment effects around Iona appear to be spatially stable based on data from 2000-2003.*
3. *Within the "effect" zone, contaminant effects are potentially possible, but unlikely, within 1 km N of the outfall. Rather, effects are typical of sediment geochemical changes related to organic enrichment.*
4. *Observed biotic effects within the Iona region are moderate to mild and can be reasonably well delineated spatially*
    a. *Biomass and abundance are not clearly affected*
    b. *Balance of polychaetes/bivalves unaltered (~95% of fauna)*
    c. *Species richness, biomass and abundance declines at the discharge are less in terms of magnitude and extent than the OE2 area outside the discharge influence*
5. *Declines in ophiuroids within the MI and LI zones is of questionable ecological significance, since they are enhanced in surrounding areas due to the localized organic enrichment.*
6. *Low values of crustaceans in the affected zone are of unknown importance, but are not an unusual occurrence in a variety of "clean" and impacted marine habitats related to a range of habitat conditions, since this is generally a sensitive group of organisms. In addition, crustaceans make up less than 1% of faunal abundance and less than 0.1% of biomass in a number of reference stations, and are thus not an important component of the infaunal community.*
7. *Declines in ophiuroids and crustaceans in the Iona "effect" zones may adversely affect selective-feeding bottom fish (particularly juveniles) and other predators, whereas the overall enrichment may enhance opportunistic predators (such as English sole).*
8. *Regional enrichment of biota such as shrimp and ophiuroids may balance or exceed adverse effects (and may help offset impoverishment occurring to the south at OE2 and sometimes OE1).*
9. *Bioturbation in the "effect" zone around Iona is likely reduced in depth due to a decline or elimination of larger fauna such as echinoderms, but may be partially offset by an increase in near-surface, smaller opportunistic forms such as small polychaetes. Related changes to "cleansing" and burial rates of contaminants are not clear, based on the current monitoring program.*

10. *Potential for bio-accumulation or magnification of toxic contaminants up the food chain needs to be addressed in a more region-wide context and is beyond the scope of this report.*
11. *Regional recruitment potential is unaffected due to the well-flushed, open location and extensive larval distribution.*
12. *Regional bio-diversity and sediment quality are not threatened.*

Of most concern at Iona is the moderately affected area within 1 km N of the outfall between about 60-90m depth. The spatial extent of this effect is not dissimilar to that of a relatively large-scale salmon net-pen operation (c.f. Burd 1997). Similar to a fallowed fish farm site, the geochemical changes are readily reversible with no long-term adverse effects, as has been shown in other discharge locations following changes to infrastructure (see Appendices C, D).

Within 3 km N of the Iona discharge, a modest decline in species richness as well as loss of ophiuroids and crustacean fauna, occurs. Sediment geochemistry indicates maximum AVS values, and thus maximum reduction in near-surface sediment oxygenation. However, there is no concurrent biomass decline, and the fauna retains both large and small members as well as reasonable levels of juvenile recruitment. Although this affected zone is not considered to be of no concern, the situation is spatially limited and temporally stable and there is currently no evidence to indicate related higher trophic level or long-term, irreversible effects.

Lions Gate Monitoring Program

The Lions Gate receiving environment has been monitored only recently. The outer part of that environment is outer Burrard Inlet. A monitoring program based on the same protocols as those used for the contemporary Iona monitoring program was initiated in September of 2002, and repeated in March of 2003 (Figure 16).

The outer Burrard Inlet is a complex system hydrographically, with a variety of known and unknown sources or locations of organic and contaminant discharge. This complexity complicates the process of identifying specific biotic effects related to specific discharges. In order to formulate hypotheses about benthic biotic effects in outer Burrard Inlet related to the Lions Gate wastewater discharge, clear identification of an exposure gradient based on reliable wastewater indicators must be identified. This exposure gradient can be explained based on reasonable estimates of deposition patterns of particulates and sediment transport.

The predicted deposition pattern of particulates from the Lions Gate discharge was originally modeled by Hodgins and Hodgins (2000b). The model predicted that the major deposition gradient would run along the north shore of the outer inlet, with a smaller deposition gradient fanning out to the south and west. Earlier sediment transport predictions (McLaren 1994) indicated that initial deposition would occur at a considerable distance from the outfall, due to high current velocity and net erosional sediments. Prior to the first sampling survey, the locations of depositional and erosional sediments were examined using a remotely operated underwater towed video.

Based on these studies, a series of exploratory sampling stations were selected within the depositional sediments fanning to the northwest and southwest away from the Second Narrows bridge (the location of the outfall), in a limited simulation of a radial gradient design as described in Environment Canada's EEM technical guidance document for Pulp and Paper benthic monitoring designs (URL: http://www.ec.gc.ca/eem/english/PulpPaper/Guidance/default.cfm).

The sampling design for benthos was not extensive, but until discharge tracers could reliably be mapped in the sediments, including a more exhaustive survey would not be useful.

Sediment chemistry measurements were taken in a more detailed suite of stations, surrounding the benthic sampling stations, to help identify either enrichment or contaminant gradients related to the Lions Gate discharge. Similar benthic monitoring surveys were carried out for some outer Burrard Inlet stations by Environment Canada in 1987, 1989 and 1995 (Burd and Brinkhurst 1990, Cross and Brinkhurst 1991, Burd 1992, Boyd et al. 1998), although the sampling methodology was different from that used in the GVRD monitoring program. Some of this historical data may be of value for assessing long-term condition of the outer Burrard inlet benthos.

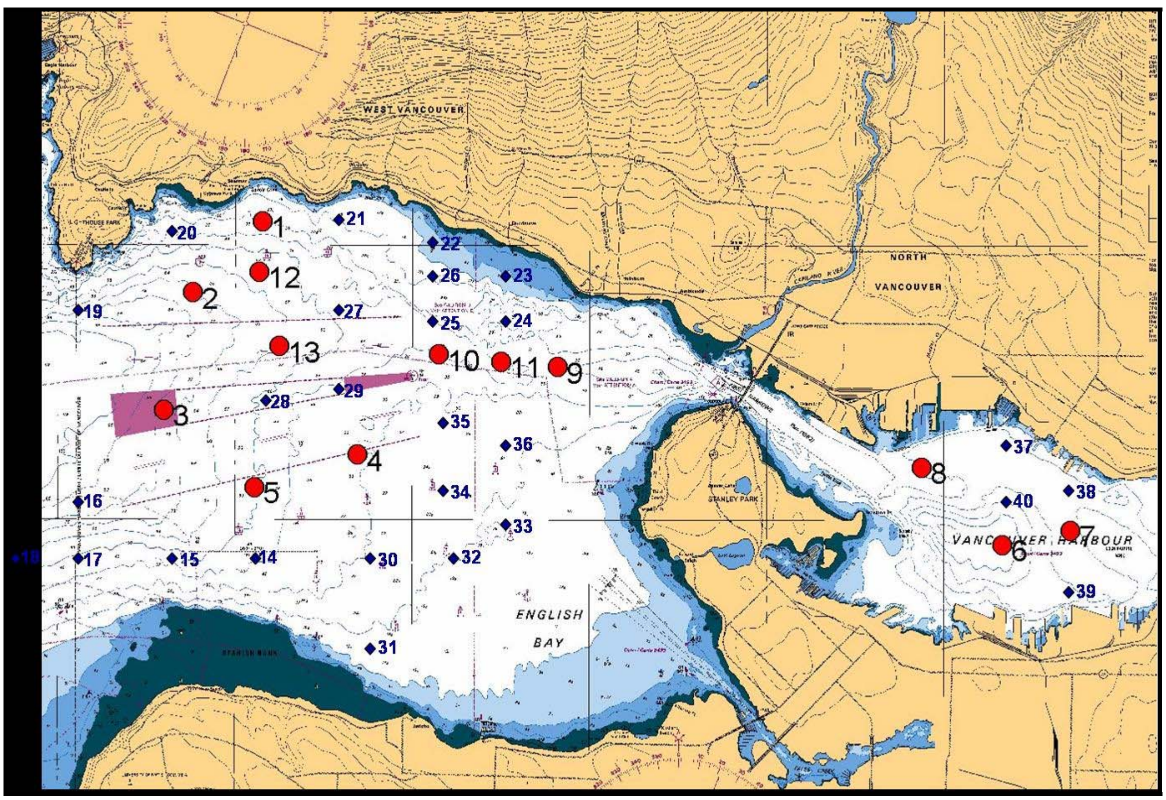


Figure 16. Benthic Sampling Station Locations for Biota (red dots) and Sediment Physical and Chemical Parameters (all stations) in the Outer and Inner Burrard Inlet

(The Lions Gate outfall is located just west of the bridge)

General characteristics of Outer Burrard Inlet benthic biota and sediment geochemistry

Based on a preliminary report on the fall 2002 initial monitoring survey for outer Burrard Inlet (Burd 2003b), some initial speculations related to the effects of the Lions gate discharge in the outer inlet can be made, but remain to be confirmed by further, more detailed monitoring surveys. Tracing the sediment footprint of the discharge is very difficult in this complex hydrographic system. Metals levels are not particularly high. However, the preliminary data from outer Burrard Inlet taken in September (post-freshet) show that Cu, Pb, Ag and Zn are strongly inter-correlated, as well as being correlated with loss on ignition (LOI) and TOC. However, TON and TOC values did not show any elevations above expected background levels for this type of sediment and habitat (all values less than 2.2 % dry wt). A detailed analysis of metals data from outer Burrard Inlet is presented in Paine (2003), but the association of metals patterns in sediments with the Lions Gate discharge remains unclear.

Except for station 6, biotic monitoring data are not yet available for inner Burrard Inlet, which is considered to be a completely separate hydrographic system from the outer inlet, with multiple and complex sources of contaminants and sediments. For this reason, station 6 was excluded from analyses.

A second survey of outer Burrard Inlet was conducted in March of 2003 (pre-freshet) and compared with the first survey and with data from the Iona survey for that year. Sediment factors and faunal patterns show a difference between September (post-freshet) and March (pre-freshet). In particular, AVS values were somewhat elevated pre-freshet, along with a striking increase in cadmium in stations 10-12 in March over the previous September.

The most reliable indicators of wastewater deposition sampled in outer Burrard Inlet were coprostanol and silver. Neither of these indicators shows a notable elevation suggestive of wastewater deposition related to Lions Gate at the stations sampled. Coprostanol data were low, but show a slight elevation at two stations, one near West Vancouver Laboratory and one off Spanish Banks. The Spanish Banks elevation may be related to the same factors causing relatively high values at the northernmost Iona station, which is just around the point to the south. It may also be related to sporadic ocean dumping in the area. However, levels in all outer Burrard stations were as low or lower than reference or background levels for the entire Iona sampling region.

AVS values did not suggest any notable sediment hypoxia except at stations 1 and 6, particularly pre-freshet. However, LOI, AVS and fecal colliforms data suggest that minor sediment geochemistry changes have occurred, particularly along the north shore, and that this sediment enrichment is associated with somewhat elevated sand and gravel deposition. Two groups of inter-related fauna were identified, one of which is relatively tolerant of moderate sediment geochemical degradation as well as organic enrichment, the other of which is relatively sensitive to sediment geochemical changes. Their distributions do not suggest adverse faunal effects in outer Burrard Inlet, but do suggest two distinct gradients of faunal patterns. A more detailed biotic assessment of the March 2003 outer Burrard Inlet monitoring data is pending.

Correlations between sediment factors and indicator taxa provide some results of note, although this analysis was done in much more detail in Paine (2003 – Appendix B):

- In September 2002 and March 2003, the metals suite showed a strong inter-correlation between copper, lead, mercury, silver and zinc (but not cadmium), suggesting a common source (see also Paine 2003 – Appendix B).
- Silver and Zinc tend to be associated with organic particulates, thus showing a high correlation with TON and TOC. The source of these metals was not clear from the sampling pattern.

- AVS values were strongly correlated with cadmium (94% in March 2003, 77% for both years combined) and moderately correlated with sand content (negatively correlated with silt/clay), suggesting some source of relatively coarse particulate enrichment which was also rich in cadmium. This is unusual, since AVS tends to be highest naturally in finer silt/clay sediments. The relationships were constant with or without the inner harbour station 6 included. Silver and coprostanol values were somewhat elevated in stations 10-12 in March 2003, but the pattern is patchy and the source is not clear.
- Organic enrichment indicators (polychaetes *Capitella capitata complex* and *Heteromastus filobranchus)*, although low in abundance, were strongly correlated with AVS, cadmium and coarse sediments.

There were some important similarities in terms of habitat and biota between outer Burrard Inlet and the Iona area. These include:

- Dominance by the bivalve *A. serricata* and other co-occurring abundant species
- Similar substrate type
- Similar proportions of major taxonomic groups
- Important indicator species noted at Iona were also found in outer Burrard Inlet

However, the overall abundance (particularly bivalves and polychaetes) and species richness values were lower in outer Burrard Inlet than the reference range values for stations 1 and 2 at Iona. In addition, SDI was somewhat lower at most stations, indicating greater faunal dominance in outer Burrard Inlet. This suggests that conditions in the inlet had strong physical (or geochemical) factors affecting faunal diversity. Bray-Curtis dissimilarity analyses show a lack of similarity between the two areas in terms of faunal composition (with and without the dominant *A. serricata* – Burd, unpublished). However, most of the Iona and Lions Gate stations were more similar to each other than to Iona stations 13 and 14 (OE2 confounded area south of IONA) or to the inner Burrard Inlet station 6.

Based on the data collected to date, it is not possible to determine what factors might be causing these biotic patterns.

Derivation of Reference Ranges and Effect Zones for Outer Burrard Inlet

Since there is no evidence of sediment wastewater deposition indicators or adverse biotic effects in benthos related to the marine discharges, it is not yet possible to determine reference locations and therefore ranges suitable for outer Burrard Inlet. Because there are numerous potential confounding influences on biotic integrity in outer Burrard Inlet, it is not currently possible to determine what the “background” biotic conditions are without the influence of the discharge. In addition to potential contaminant inputs, there are undetermined physical impacts, which may affect biota. These may include bottom anchor and line dragging from shipping, and patchy ocean dumping effects.

Biotic reference ranges estimated for the Iona monitoring program northernmost stations should be of most relevance for outer Burrard Inlet (see Table 23). Although Iona station 1 data is somewhat confounded due to higher sand content than outer Burrard stations, values for station 2 would provide reasonable reference ranges. The southern reference stations for Iona tend to be significantly different from the northern ones in terms of faunal composition, and thus are not reliable as reference stations for outer Burrard Inlet. Table 23 includes existing “reference” ranges based on the 95th percentile of the cumulative frequency distribution for the biotic factors

listed based on the assumption that all stations except 1 (most shallow) and 6 (inner Vancouver Harbour) were in background condition (i.e., unaffected by the Lions Gate discharge).
listed based on the assumption that all stations except 1 (most shallow) and 6 (inner Vancouver Harbour) were in background condition (i.e., unaffected by the Lions Gate discharge).

Ecological Significance of Benthic Biotic Effects at Lions Gate

The same ecological ramifications as noted for Iona above are important for the benthic fauna and higher trophic levels in the Lions Gate receiving environment. No clear detrimental effects on benthic fauna have been noted to date in outer Burrard Inlet, although several stations had unusual features (low species and abundance at station 2, low SDI at station 12), and Paine (2003) notes that elevated metals levels higher than those in the Iona receiving environment may have the potential for biological impact. However, the elevated metals levels are not clearly related to the Lions Gate discharge. There is no evidence of notable enrichment in the form of enhanced abundance of known opportunists, or organic enrichment of sediments (TOC or AVS). Therefore, it cannot be concluded that there are any effects of concern to the benthos related to the Lions Gate discharge in this area. However, with one pre- and one post-freshet survey completed, there is currently insufficient information to make any conclusions with confidence.

Long-term cumulative effects of toxic contamination in the entire Burrard Inlet system from a variety of diffuse and point sources may be a more regional and inter-agency concern, but cannot be addressed in the monitoring program for the marine discharges.

Table 23. Minimum and Maximum Ranges for 2001 and 2002 Iona stations 1,2 compared iwth Minimum and Maximum Values for stations in Outer Burrard Inlet for Sept 2002 (excluding stations 6,1) and Reference Ranges for Same Locations in March

Note: minimum and maximum ranges for Lions Gate stations are considered equivalent to 95th percentile values due to the limited data available to date.

	IONA 2001,2002		LIONS GATE 2002	
Factor	Min Sta1,2	Max Sta 1,2	Min LG	Max LG
Total abundance	688	1689	217	1065
Species richness	73	84	34	81
Bivalve abundance	410	866	139	665
Crustacean abundance	10	39	5	34
Polychaete abundance	231	395	61	348
Ophiuroid abundance	9	100	0	53
%bivalves	44	66	47	73
%crustaceans	1	3.4	1	6
%polychaetes	21	45	20	47
% Capitella capitata abun	0	1	0	0
%Heteromastus filobranchus abun	0	<1	0	<1
Axinopsida serricata abun	204	653	92	464
Biomass (without holothurians)	21	48	6	24
Swartz Dominance Index	10.5	16.5	4.5	12
BC dissimilarity to IONA 1,2	0.3	0.4	0.5	0.8

Table 23. continued

Factor	IONA 2003		LIONS GATE 2003	
	Min Sta1,2	Max Sta 1,2	Min LG	Max LG
Total abundance	964	1105	391	933
Species richness	72	90	46	78
Bivalve abundance	514	728	217	594
Crustacean abundance	7	20	8	51
Polychaete abundance	214	318	60	256
Ophiuroid abundance	29	47	0	45
%bivalves	59	66	35	67
%crustaceans	0.6	17	1	4.3
%polychaetes	25	31	12	28
%*Capitella capitata abun*	0	1	0	<1
%*Heteromastus filobranchus abun*	0	<1	0	1.4
Axinopsida serricata abun	300	584	147	431
Biomass (without holothurians)	17	40	12	58
Swartz Dominance Index	9	12.5	4.2	13.5
BC dissimilarity to IONA 1,2	0.3	0.4	0.5	0.7

4.3.4 Cautions, Warnings and Triggers Framework for Iona and Lions Gate

The identification and characterization of “warnings” and “triggers” are two levels of one basic process in the development of this document. However, in order to identify warnings and triggers, two other concepts must be understood and quantified. These are “reference” or “background” variability (related to Cautions) and “exposure” indicators.

Indicators (Exposure, Warning and Trigger)

Warnings and Triggers must be based on some tangible indicators, which can be used to assess change from reference condition. In order to be meaningful, these indicators must be reliable for showing a specific type of response that can be judged as to its ecological significance, and for being affected by the specific type of impact known to result from exposure to wastewater. These are “exposure” indicators. By definition, all warning and trigger indicators must also be exposure indicators. If the link cannot be made between the indicator and the discharge in question, then the indicator has no useful meaning in the development of this document.

Exposure indicators are important in the trigger process because they provide a context of the spatial and temporal extent and magnitude of exposure of the receiving environment to the discharge. Exposure levels may be descriptive or statistical, and their coincidence with the discharge reasonably certain to conclude cause and effect. The definition of exposure levels would be determined by best professional judgment from experts.

Exposure indicators should be distinguished from warning indicators. The former implies that the indicator has been subject to particulate deposition from the discharge in question, or “exposed” to the discharge, whereas the latter shows a measurable receiving environment effect, which may in the future, be associated with an ecological change of concern. Thus by definition, warning indicators are a smaller subset of exposure indicators.

Trigger indicators will comprise a very limited sub-set of warning indicators, for which there is strong confidence in the statistical characterization of natural variability, as well as a pressing ecological imperative (or links to ecosystem, fisheries or human health issues) related to the indicator in question. However, trigger indicators may also be exposure indicators that do not have a tangible or statistically measurable intermediate or "warning" level. Trigger indicators can reliably be used to project unacceptable environmental effect levels (AEL's) at some time in the future.

Levels (Reference, Caution, Warning and Trigger)

Reference

In the absence of widely accepted and rational guidelines for determining the level of impact in a receiving environment from a specific type of stressor, it is necessary to assess impact based on what is "normal" for the area in question. This is most accurately described as "background" conditions. It is not possible in a highly urbanized area to project pristine or pre-development conditions, rather it is only possible to assess current conditions in the general region which are outside the influence of the stressor in question (wastewater discharges) and not subject to any other severe anthropogenic impact. It is impossible to avoid some anthropogenic influences in southern Georgia Strait. It is the incremental influence from the discharges, which are being assessed for the purposes of avoiding detrimental ecological effects via the development of warnings and triggers. This background condition will be referred to as "reference" for the purposes of this document. Therefore, warning and trigger levels must be based on some level of change from what is considered "background" or "outside the discharge influence".

Reference levels for all types of indicators must have measurable boundaries; this can be done statistically, using confidence intervals or percentile ranges. The boundaries imply that there is natural variability within the background condition of the indicator in question. This natural variability must be measured spatially and temporally with a reasonable degree of confidence before the indicator can be used in the warning and trigger framework. Within this range of natural variability, it is not possible to detect a change of concern in any indicator.

Caution

Natural variability is subject not only to the whims of nature, but also to the vagaries of sampling methodology. Caution levels provide a means to continuously assess the performance of reference levels for indicators, and provide a means to check for unexpected influences external to the discharge (natural or anthropogenic) in the receiving environment, changes in sampling or analytical methodology for monitoring programs, or long-term natural environmental or biological cycles. The results of the on-going Ambient Monitoring Program (Appendix G) for southern Georgia Strait provide further verification of the validity of reference ranges.

Specifically, a caution level is reached when the reference ranges change from historical levels outside a pre-determined margin dictated by the accuracy of the sampling methodology.

Warning

The use of warning levels implies that the warning indicator value has changed outside pre-existing boundaries. By definition, the warning indicator is not only related to the discharge exposure, but a change in level reflects a potential ecological effect of concern. However, a warning level would not be considered immediately detrimental or indicative of ecological degradation. Such changes may be within the assimilative capacity of the environment, and thus may provide a “stable” affected condition that is not of concern. However, the trend of change in a direction that may in the future become detrimental constitutes a “warning”. Therefore, the warning level reflects (is related to but not necessarily the cause of) a statistically significant change in an appropriate warning indicator(s), from existing conditions as defined over space and time in the monitoring programs, which can be reasonably attributed to the discharge.

When warning levels are reached, the cause of the change or trend in the indicator(s) must be determined. When warning levels are met, the on-going monitoring program may be sufficient to track the indicator of concern, or more intensive monitoring may be implemented.

Trigger

Trigger levels by definition must be more rigid and limited than warning levels. Because trigger levels will prompt some action, which can have far-reaching societal, health and economic implications, they must be extremely reliable, preferably with extensive historical and monitoring precedent in other jurisdictions as well as the receiving environment in question. The criteria for selecting trigger levels must be the most thorough and carefully conceived of the three levels, and be clearly related to the discharge. Trigger levels are reached when the appropriate indicator shows a degree of change, which does not yet show unacceptable ecological degradation, but will in the foreseeable future if not reversed. This “trigger” level must be based on sound statistical extrapolation and extensive research and experience in other jurisdictions.

Figure 17 shows the hierarchical relationship between indicators and levels for the benthos component of this document. Inherent in this scheme are the following precepts:

- Statistically measurable changes related to the Iona discharge are spatially and temporally stable and limited in scale, and thus do not currently show ecological effects of concern for the region.
- Biotic and sediment geochemistry changes related to the Lions Gate discharge are not evident in outer Burrard Inlet based on the current monitoring program.
- Caution levels are based on deviations from historical reference conditions, taking into account acceptable sampling precision based on the existing monitoring programs.
- Warning levels are based on negative changes from existing conditions in the affected zones, taking into account acceptable sampling precision based on the existing monitoring programs.
- Trigger levels are based on negative changes in the affected zones past the warning level, which also show a trend that may result in degradation in environmental quality in the foreseeable future.

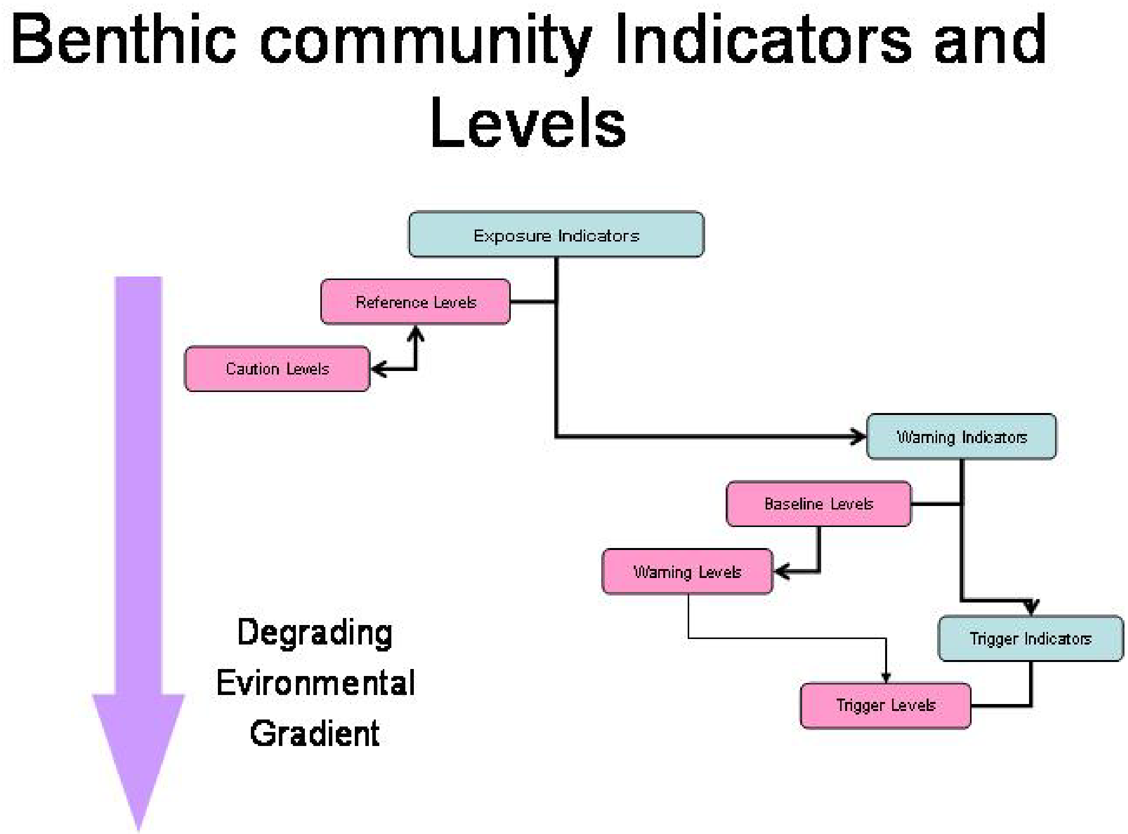


Figure 17. Flowchart illustrating the relationship between exposure, warning and trigger indicators and levels for marine benthic habitats

Environmental Effects of Concern

In order to provide warnings and triggers, the indicator in question must be relatable to the wastewater discharge with reasonable confidence. In the case of warning indicators, complete confidence is not required because reaching a warning level tends to result in detailed and timely investigation of the cause before further action is taken. However, triggers must be clear-cut with no room left for doubt about the cause. In some cases, a given indicator may have both warning and trigger levels. Other indicators may be useful only for one or the other purpose. In summary, the degree of confidence is much higher in a trigger indicator than in a warning indicator.

A further distinction between warning and trigger indicators is that warnings may relate to indeterminate changes in wastewater particulate exposure in sediments and biota. In other words, a relative change in sediment exposure may result in a warning event, but there is no indication as to whether there has been a change in some negative and unacceptable environmental impact. However, a trigger event clearly implies that an unacceptable environmental impact will, or is likely to occur.

Before warning and trigger indicators can be selected, the types and spatial extent of effects of concern related to the discharge must be identified and prioritised to allow selection of warning and trigger indicators. For liquid waste discharges, these effects may include the following:

1. Change to substrate character from sand discharge at end of pipe (patchy habitat heterogeneity can actually increase overall species diversity in the area)
2. Increased sedimentation rate in the maximum deposition zone (physical effect due to burial and clogging)
3. Reef effects from pipeline (predation and effects on benthic community) within about one km of the discharge (see Appendix D)
4. Increased levels of known or probable toxic constituents in sediments above background levels for the region (see Chapter 3)
5. Increased carbon and/or nitrogen loading to sediments of the area
6. Changes in habitat geo-chemistry resulting in sediment oxygen declines, and increases in hydrogen sulphide and other potentially toxic constituents in the benthic habitat
7. Faunal enrichment
8. Faunal impoverishment (species, taxonomic groups, entire communities)
9. Increases in fish and macro-invertebrate pathological damage (Bailey *et al., 2003*)
10. Increases in concentration or spatial extent of human pathogens (bacterial, viral)

Effects of concern in this case are those outside what might occur naturally under various habitat conditions. Effects related to the first three items can and do occur naturally (and anthropogenically) throughout the Georgia Strait region. For example, some of the highest particulate deposition areas in B.C. occur near the mouths of the Fraser River, particularly during freshet. Sandy depositions occur naturally in the region in relation to hydrodynamic conditions as well as Fraser River and other land-based discharges. In itself, this is only a concern if the deposition rate is so high that all fauna are wiped out (c.f. Burd 2002b). In the Iona and Lions Gate areas, the relatively minor additional particulate deposition may serve to change the character of benthic communities but cannot rationally be considered an “adverse” effect. The reef effect is relevant to understanding the “effluent” versus physical effects from the pipeline, yet is not feasible in terms of mitigation. Any marine structures (of which there are many in the lower Georgia Strait) may cause this effect. Thus, the reef effect becomes a confounding factor rather than an “effect” to be addressed, raising the issue of how close to the outfall monitoring should take place.

Item 5 - increased carbon or nitrogen loading to the area has been identified as the primary concern under salmon net cages, at some pulp mills and at other wastewater discharges world-wide. This issue is a concern only if the sediments and microbiota in the area cannot assimilate the additional organic load resulting from the discharge of primary-treated wastewater. At Iona, sediments do not show any notable increase in organic material related to the discharge, even though particulate modelling clearly shows an increased delivery to sediments from the discharge. Thus, organic loading per se is not an “adverse” effect. However, since sediment organic content has not shown an elevation at IONA or outer Burrard Inlet (relative to Lions Gate) to date, any notable change in that condition in these areas could be important as a “warning”.

Item 6 is also related to organic loading. Even when sediment levels do not indicate an accumulation of organic material, increased organic loading can cause a geochemical response in sediments by stimulating bacterial activity. There has been a great deal of research related to the amount that sediments can assimilate before notable geochemical changes (decreased oxygen, increased hydrogen sulphide, outgassing of other potentially toxic constituents such as arsenic, methane, etc.) occur (for review see Burd 2003a – Appendix D). Such negative geochemical changes can affect sediment biota, depending on the spatial extent and magnitude of the deposition and the assimilative capacity (mostly related to rate of delivery of oxygen to sediments, oxygen porosity, etc.). Therefore, this is an effect of concern. Because the biotic effects of sediment geochemical degradation are relatively well studied, geochemical indicators may be useful in support of both warnings and triggers.

Item 7 - faunal enrichment - is a common phenomenon in areas with increased organic loading. This occurs naturally in many habitats, particularly when there is considerable riverine input. Faunal enrichment alone, without any impoverishment, simply increases the biomass of sediment biota available to feed higher trophic levels. Therefore, it can actually stimulate fisheries production. This condition implies that there are no adverse geochemical effects occurring in sediments. Faunal enrichment is not an effect of concern.

Item 8 - faunal impoverishment - is a concern. When the impoverishment can be attributed with reasonable certainty to the discharge and is extreme enough to have serious consequences on the stability of the benthic community and higher trophic levels, it is a negative impact of concern and should be addressed by warnings and triggers.

The monitoring program is not designed to examine Item 10 - increases in human pathogens. However, there may be warning levels of sediment fecal colliforms, which would lead to special investigations of the distribution of human pathogens. The presence of colliforms in sediments is not known to be of concern to the biota, and is not known to transmit to higher trophic levels through any pathway. Colliforms are short-lived in marine sediments and tend to be readily out-competed by native bacterial populations; however, they are good indicators of recent wastewater deposition.

4.4 BENTHIC INDICATORS, CAUTIONS, WARNINGS AND TRIGGERS FOR IONA AND LIONS GATE

Based on an Ecological Assessment of effects at Iona and a rigorous monitoring program, it was concluded that effects are clearly evident but of relatively minor ecological concern. In outer Burrard Inlet, it is not possible to identify a footprint for discharge-related solids deposition, thus benthos are not considered adversely affected by the discharge. Therefore, risk assessment and action plans are based on significant and measurable changes from the current condition, but prior to causing significant adverse ecological impacts.

4.4.1 Selection of Indicators and Zone of Application

INDICATORS are indicative of discharge organic enrichment effects, which can indicate adverse biotic/geochemical changes. The selection of indicators depends on:

1. Reference ranges (can't use if too close to 0)
2. Consistency in magnitude and pattern
3. Potential for outside factors to affect
4. Ecological relevance to organic enrichment and health of community
4. International recognition as indicator

Based on results of the Iona 2000-2003 monitoring programs (EVS 2001;2003, Bailey et al. 2003) and results of research and discussion documents prepared for GVRD (Burd 2000, 2002a, 2003a - see Appendices C and D), a number of potential exposure, warning and trigger indicators have been identified for the receiving environments of the marine discharges. Before any of these can be selected, they must be analysed with respect to the conditions listed above. These are primarily macrobiotic (benthos) indicators. However, physical or sediment organic geo-chemistry indicators are significant since it is the dynamics of changes in sediment geo-chemistry, which tends to affect the biota most profoundly. Microbiotic indicators may be important in linking the geo-chemistry and biotic changes. Finally, wastewater-specific indicators are included to ensure that any biotic changes can be reliably related to the discharge rather than confounding factors.

Based on these considerations, Table 25 includes selected exposure indicators based on results in Tables 22-24, which may be suitable for caution, warning or trigger levels. Table 24 illustrates that some of the exposure indicators are confounded by factors other than the liquid waste discharges, or may not have acceptable statistical precision. This does not eliminate them as candidate indicators, but rather, qualifies how they can be used (see section 4.4.2 below).

The only indicator included in Tables 22 and 24 which has not been discussed in the aforementioned research documents is the pattern of iron or manganese oxide staining present on the dominant bivalve *Axinopsida serricata*. Data are complete for Iona in 2001, 2002 and 2003, and a primary literature publication on this indicator is in preparation. Briefly, the indicator recommended for use is the occurrence of adult live animals with shell staining in the 0 (no stain) or 1 (very faint stain) categories, which is significantly related to the sediment geochemistry. In well-oxygenated sediments, iron and/or manganese oxide stains occur because the metals are precipitating out on the shell margins as the animals respire and grow. However, where organic enrichment has reduced sediment oxygen and increased hydrogen sulphide production, the metals are more likely to react with sulphide and/or be mobilized and released into the water column. Therefore, the reddish staining is either much reduced or absent. Thus, the staining in adults is a long-term indicator of sediment geochemical conditions in which the bivalves are living. A regression between AVS values and adult shells with 0/1 staining for all years produces an adjusted r^2 value of 0.7 (70% of variance explained, Burd, unpublished).

Table 25 then summarizes the selection of relevant indicators to be used in cautions, warnings and triggers for various effect zones identified using benthic biotic patterns in the marine receiving environment of the GVRD wastewater discharges.

Table 24. Candidate indicators for use with caution, warning and trigger levels for Iona and Lions Gate

Indicator	Where Enhanced	Where impoverished	Statistically distinct Effect Zones	Consistency in Pattern	Consistency in Magnitude	Outside effects evident?	Reference precision <20%	Recognized other jurisdictions?
Biotic								
A. serricata abun	BE	MI	no	yes	moderate	yes	yes	no
% bivalves	LI	MI	no	yes	yes	no	yes	no
% polychaetes			no	no	no	no	no	yes
% echinoderms	BE	MI,LI	yes	yes	yes	yes	no	yes
% crustaceans		MI,LI	yes	yes	yes	yes	no	yes
SDI	MI	MI,LI	no	yes	no	no	no	yes
Richness		MI,LI	no	yes	no	yes	yes	yes
Abundance	BE	MI	no	no	no	yes	yes	yes
Bray-Curtis dissimilarity	MI,LI	R,BE**	yes	yes	yes	yes	n/a	no
Geochemical								
AVS	MI,LI	R,OE2	yes	yes	yes	no	no	yes
A. serricata shell staining	R	MI,LI,BE	yes	yes	yes	no	n/a	no
Microbiotic								
Fecal colliforms	MI,LI	R,OE2	sometimes	moderate	no	no	no	no
Contaminant								
Coprostanol	MI,LI,BE		yes	yes	no	no	n/a	no
4-Nonylphenol	MI,LI,BE		yes	yes	yes	no	n/a	yes

Table 25. Selected Indicators, Types and Zones of Application

	ZONE OF APPLICATION		
Indicator	**Caution**	**Warning**	**Trigger**
Echinoderm abundance	R	BE	
Crustacean abundance	R	BE	
%*Capitella capitata complex*	R	MI,LI,BE	MI,LI,BE
%*Heteromastus filobranchus*	R	MI,LI,BE	MI,LI,BE
%bivalves	R	MI,LI,BE	MI,LI,BE
Swartz Dominance Index	R		
Species richness	R	MI,LI,BE	MI,LI,BE
Bray-Curtis dissimilarity	R	BE	
Axinopsida serricata %adults with 0/1 stain on shell	R	BE	
Sediment fecal colliforms	R		
Sediment AVS	R	MI,LI,BE	MI,LI,BE
Sediment 4-nonylphenol	R	MI,LI,BE	MI,LI,BE

4.4.2 Deriving caution, warning and trigger levels for selected indicators

It is important to distinguish between the use of absolute levels versus relative changes from some background level. In many cases, it may be possible to be reasonably confident in the short-term natural variability of an indicator, but not in long-term climatic or cyclical changes. This can be due to insufficient long-term data on natural variability or due to insufficient scientific knowledge about the specific ambient levels necessary to produce known biotic effects. This is particularly true of "trigger" levels, which can have far-reaching consequences. This issue must therefore be considered carefully for each indicator. The following set of questions illustrates the background work that has been required to determine rational warning and trigger levels.

What criteria are appropriate for determining warning and trigger levels?

- Statistical variability
- Existing guidelines
    - Canada (CCME, BC Ministry of Environment 1990)

    - Washington State (DOE, PSRP)
    - Southern California
- Toxicity data
- Scientific Literature related to effects of organic enrichment
- Ecological (trigger levels)
    - What levels reflect fundamental shifts in community dynamics?
    - What levels might affect higher trophic levels?
    - What levels might affect local fisheries?
    - What levels might affect human health?
- Physical
    - At what level of deposition does organic recycling change to organic storage and thus habitat degradation?
    - Is the surface 1-3 cm of sediment well mixed and oxygenated?
    - What is the relative contribution and pathway for Fraser River sediments into the area?

Are Warning and Trigger Levels affected by changes in only one indicator, or a minimum combination of indicators?

At Iona the presence of profound confounding influences in this heavily urbanized and industrial area dictate that the isolated use of biotic or geochemical indicators can be dangerous for determining warnings and triggers. Based on our knowledge of the biotic effects related strictly to the discharge from the detailed Iona work, combined sets of indicators can be used to isolate the effects of wastewater particulate deposition. Since sediment organic enrichment and related geochemical changes have been suggested to cause most of the biotic effects observed, warning and trigger levels should be based on biotic indicators coupled with reliable geochemical indicators, which cannot be expected to be related to any of the existing confounding influences in the area.

Also acknowledged is the potential that sources of organic enrichment other than liquid waste discharges may occur in the receiving environments. This is particularly true for outer Burrard Inlet. Therefore, any geochemical and biotic indicators used for warnings and triggers must be linked with a concurrent wastewater-specific indicator for the discharges, such as coprostanol, 4-nonylphenol, or silver (see Chapter 3). Of these, 4-nonylphenol is measured over a reasonable concentration range, is relatively consistent in magnitude and patterns over time and is considered an excellent indicator of wastewater effluent (Chapman and Paine 2000, Bailey et al. 2003).

At Lions Gate, the confounding influences are almost overwhelming. The Burrard Inlet Environmental Action Program (BIEAP) (1998) recommends a weight of evidence approach for determining if specific sites in Burrard Inlet are adversely affected or unaffected. Because of the limited data available for outer Burrard Inlet to date, a similar indicator combination for trigger levels is suggested as that designed for Iona.

Should Warning and Trigger levels be the same for all locations relative to a particular discharge?

Section 4.3.3.1 above details the known zones and character of effects within these zones for Iona (see also Appendix D). . Effects along a potential organic enrichment gradient range from moderate (MI: within about a 20 m depth band within 1 km N of the outfall), through low (LI: 1-3 km N), enriched (BE: 3-4 km N, 1 km S) and background. Further south, a fluctuating area of moderate biotic effects is unrelated to the discharge and different in character to what would be expected from organic enrichment.

Warning and trigger levels are specifically designed to detect significant changes from the existing condition in each of the effect zones. Because the character of effects is typically the same in MI and LI, and differences in the extent of effects cannot be statistically distinguished between these two zones (Burd 2003a), warning and trigger levels are typically calculated for this combined "impoverishment" effect zone. Warning and trigger levels for the biotically enriched (BE) zone are considered separately because the types of biotic changes are different in this zone relative to the impoverishment zone.

Based on existing monitoring data for outer Burrard Inlet, no clear "effect" zones that can be attributed to the Lions Gate discharge have been identified. For this reason, the indicators and approach to determining caution and trigger levels are the same as for Iona; however, warning levels for affected zones do not apply. The outer Burrard Inlet levels are considered interim only, until temporal variability can be assessed. The monitoring effort will continue, but biotic effects related to the discharge appear at present are undetectable.

Since the LWMP implicitly assumes that current environmental conditions in the receiving environments of the marine discharges are not of concern and are stable over time, warning and trigger levels are based on adverse changes to these conditions in each of the identified effect zones. Lions Gate has no deposition footprint; therefore, warnings and triggers must be applied to all parts of the outer inlet.

What are statistical limits for reliability in assessing changes in selected indicators?

The reference range for indicators is based on the 95th percentile of the cumulative frequency distribution for reference samples over time. This 95th percentile represents the statistical reliability of the indicator for detecting change. Caution and trigger levels for the Iona discharge area are based on these reference ranges, which incorporate temporal and spatial variability measured over 4 years (2001-2003). Caution and trigger levels for outer Burrard Inlet are derived based on the existing 95th percentile ranges for all stations except 6 (Inner Burrard Inlet) and 1 (depth confounded) for the March 2003 monitoring data. In practice, the 95th percentile values for outer Burrard Inlet are the same as the minimum and maximum data ranges shown in Table 23, since there is currently data for only one monitoring season available for defining reference ranges.

However, the 5% of the reference samples which are outside the reference range may be related to patchiness in sampling. Since a sampling precision (SE/mean) of <20% is considered acceptable for benthic marine grab samples (see Burd et al. 1990 for review) collected in the monitoring programs for Iona and Lions Gate, it is understood that a given sample may fall a maximum of 20% below the limit of the 95th percentile reference range due to environmental patchiness related to the sampling method used. Therefore, a change of >20% outside existing 95th percentile limits for cautions and warnings is considered to be a reliable and "real" change in the condition of the indicator in question.

For trigger levels, different, non-statistical criteria are used. This is because triggers should represent a change of sufficient magnitude wherein imminent adverse biotic effects are expected. Such levels are difficult to predict before there are locally relevant examples to observe, but can be estimated based on best professional judgment, on international research and experience in other jurisdictions, and on the vast wealth of information available in the literature on the nature and consequences of extensive organic enrichment effects in marine habitats.

At the observed rate of change, when will the factor(s) reach unacceptable or trigger levels?

Answering this question will potentially require modeling and/or statistical projections. This type of analysis would presumably be done if warning levels were exceeded.

Biotic and Geochemical Cautions

Note that Cautions for Lions Gate cannot be based on reference ranges because no specific reference stations have been identified to date in the monitoring program. Therefore, cautions for outer Burrard Inlet are given as the 95th percentile range for the 2003 data for all stations except 6 (inner Burrard Inlet) and 1 (confounded due to depth). In addition, not all indicators originally identified as suitable for cautions, warnings and triggers can be used for the outer Burrard Inlet area, either because their ranges overlap zero, or because they have not currently been measured. The Caution levels for outer Burrard Inlet are considered interim, because there is insufficient monitoring data to determine temporal variability. Caution levels for 4-nonylphenol are derived strictly from the Iona data, since biotic effect zones related to a wastewater discharge can be clearly delineated, and measurements are not currently available for outer Burrard Inlet.

Definition**:** Cautions are a means of providing early indication of changes in background reference conditions in the selected stations for each discharge. Caution levels apply when any new reference samples fall outside +/-20% of existing reference ranges (this accounts for spatial heterogeneity based on the sampling procedure, or precision)
Function: Cautions are used for annual confirmation or re-calibration of Reference Ranges (95th percentile for R zone (calculated over all previous years)
Indicators**:** See indicators listed in Table 25
Levels: Caution levels based on 95th percentile reference ranges +/- 20% (as appropriate) are given in Table 26 for Iona and Table 27 for Outer Burrard Inlet. For further details on reference ranges, see original ranges described in Table 22 for Iona and Table 23 for Lions Gate
Supporting Indicators**:** see Tables 26 and 27

> In order to confirm that changes in reference levels are related to the liquid waste discharges, the deviation from reference condition must be accompanied by an increase in both a geochemical indicator of sediment enrichment (AVS) and a reliable sediment contaminant indicator of wastewater exposure (4-nonylphenol). A notable increase in AVS is determined as an increase over 95th percentile +20% values for the relevant zone. A notable increase in 4-nonylphenol is determined as an increase over 95th percentile +20% values for the relevant zone. For reference zones, the 4-nonylphenol increase is equivalent to about 10% of the CCME Interim guidelines for expected Toxic Equivalent Units for marine sediments at TOC = 1% (CCME 2002).

Response: Determine reason, i.e., field or lab processing, evidence of outside effects
Result**:** Exclude confounded reference sample or re-calibrate reference ranges

Biotic and Geochemical Warnings

Note that Warnings apply to affected zones in the Iona receiving environment. Because all existing stations monitored in Burrard Inlet (except 1 and 6) are considered to be in "reference" condition, Warnings for enriched or impoverished zones are not applicable.

Definition**:** Warnings are used to provide early indication of changes from existing condition in the zones affected by the discharge (impoverished or enriched; MI,LI,BE at Iona, none at Lions Gate).
Function: The changes that result in Warnings are not known to be ecologically detrimental, but may ultimately lead to detrimental effects if the direction and rate of change continue. Thus, warnings provide a means to prevent and/or reverse conditions which have resulted in the attainment of a Warning Level.
Indicators: see Table 25
Levels**:**

- Warning for impoverished zones at Iona (MI,LI): Based on estimated historical MI,LI range (95th percentile for data from 2001 to 2003 combined +/-20%), any 3 replicate samples outside this range in MI or LI zones for 2 sampling years (see Table 26)
- Warning for biotically enriched zones (BE) at Iona: Based on estimated historical BE range (95th percentile for data from 2001 to 2003 +/-20%), any 3 replicate samples outside this range in BE or R zone for 2 sampling years (see Table 26)

Supporting Indicators (see Tables 26):

- In order to confirm that biotic warnings are related to the discharge, the biotic warning levels must be reached concurrent with notable increases in both a geochemical indicator of sediment enrichment (AVS) and a reliable sediment contaminant indicator of wastewater exposure (4-nonylphenol). A notable increase in AVS is determined as an increase over 95^{th} percentile +20% values for the relevant zone. A notable increase in 4-nonylphenol is determined as an increase over 95^{th} percentile +20% values for the relevant zone, equivalent to 40% (impoverished zones) or 18% (enriched zones) of the CCME Interim guidelines for expected Toxic Equivalent Units for marine sediments at TOC = 1% (CCME 2002) for zones MI and LI, and 18% of CCME TEU for zone BE.

Response**:**

- ***Warning Response 1***: Identification of cause (sampling or processing error, increased organic loading, natural region-wide phenomena, outside existing or new effects, etc.)
- ***Warning Response 2***: If discharge is source – risk assessment of temporal trend and determination of best means to mitigate
- ***Warning Response 3*****:** – intensified sampling to confirm identification of cause and predict progression towards trigger status

Result**:** Stop and reverse trend towards triggers, return indicators to baseline levels or better for each zone

Biotic and Geochemical Triggers

Definition**:** A level for the indicator(s) has been reached which reflects probable ecological deterioration of concern in the receiving environment. Attainment of a trigger requires immediate action to reverse the trend.
Function: To prevent deterioration of the ecological condition past warning levels to levels of ecological damage to the benthic receiving environment related to organic enrichment from the discharge.
Indicators: see Table 25
Levels**:**

Triggers for all zones: Based on change from historical condition, past warning levels, to +/- 50% of reference ranges (based on 95th percentile ***for a given year*** – see Tables 22 and 26 for Iona and Tables 23 and 27 for Lions Gate for reference levels and trigger levels) for any 3 replicate samples over 2 sampling years for:

a. Change in proportion of bivalves concurrent with significant increase in AVS and 4-nonylphenol (see “Supporting Indicators” below and tables 24,25)
b. Change in Species Richness concurrent with significant increase in AVS and 4-nonylphenol (see “Supporting Indicators” below and tables 26,27)
c. Increase in either *C. capitata* or *H. filobranchus* to 25% of total fauna concurrent with significant increase in AVS and 4-nonylphenol (see “Supporting Indicators” below and Tables 26,27)

Trigger for BE zone only (Iona):

a. Loss of all echinoderms and crustaceans concurrent with significant increase in AVS and 4-nonylphenol (see “Supporting Indicators” below and Tables 26,27)

Supporting Indicators (see Tables 26,27):

- In order to confirm that biotic triggers are related to the discharge, the biotic triggers must be reached concurrent with a significant increase in both a geochemical indicator of sediment enrichment (AVS) and a reliable sediment contaminant indicator of wastewater exposure (4-nonylphenol). A significant increase in AVS is determined as a 100% increase over 95^{th} percentile +20% values for the relevant zone. A significant increase in 4-nonylphenol is determined as reaching 60% of the CCME Interim guidelines for expected Toxic Equivalent Units for marine sediments at TOC = 1% - CCME 2002).

Response**:**

- ***Trigger response 1***: Identification of cause (sampling or processing error, increased organic loading, natural region-wide phenomena, confounding effects, etc.); note that this first response is of particular importance in outer Burrard Inlet, where numerous diffuse and point source inputs may be potentially affecting benthos
- ***Trigger response 2***: If discharge related, review mitigation plan with EMC and present to province
- ***Trigger response 3*****:** Implement approved mitigation

Result**:** Reverse trend of adverse changes before unacceptable biotic or habitat degradation occurs.

Table 26. Caution, Warning and Trigger Levels for selected Indicators at Iona

Zones are; MI = moderately impoverished; LI = low impoverishment; BE = biotically enriched; R = reference (See Figure 4 - check this figure number)

IONA RECEIVING ENVIRONMENT	**ZONE OF APPLICATION**		
Indicator	**Caution (95th percentile for Reference +20%)**	**Warning (affected zone 95th percentile +20%)**	**Trigger (biotic) and supporting guidelines** (geochemical and contaminant)**
Echinoderm abundance	R (<15)	BE (<19)	BE (<2)
Crustacean abundance	R (<5)	BE (<30)	BE (<2)
%*Capitella capitata complex*	R (>1.2%)	MI+LI, (>8.8%) BE (>3.1%)	MI,LI,BE (>25%)
%*Heteromastus filobranchus*	R (>1.2%)	MI+LI (>5%) BE (>2%)	MI,LI,BE (>25%)
%bivalves	R (<34%)	MI+LI, BE (<30%)	MI,LI,BE (<50% reference levels for that year – see Table 1)
Swartz Dominance Index	R (<4)		
Species richness	R (<53)	MI+LI (<37), BE (<56)	MI,LI,BE (<50% reference levels for that year – see Table 1)
Bray-Curtis dissimilarity	R (>55%)	BE (>78%)	
Axinopsida serricata %adults with 0/1 stain on shell	R (>8%)	BE (>54%)	
Sediment fecal colliforms	R >(150)		
AVS	R (>2.4)	MI+LI (>21.4) BE (>6.6)	**MI+LI (>43), BE (>13.2)
4-nonylphenol	R (>60 ug/g dry wt ~9% CCME TEU)	MI+LI (>40% CCME Interim guidelines for TEU with TOC=1%) BE (>18% CCME TEU)	**MI+LI (>60% CCM Interim guidelines for TEU with TOC=1%; **BE (>30% CCME TEU)

** NOTE AVS and 4-nonylphenol levels are not triggers per se, but guidelines in support of liquid waste discharge as causative to biological triggers

Table 27. Caution Warning and Trigger levels for selected indicators at Lions Gate

Note that warning levels do not apply since there are currently no impoverished or enriched zones identified in relation to the Lions Gate discharge. Caution Ranges are given as 95th percentile of distribution (+20%) for all of the 2003 data (except stations 1 and 6).

OUTER BURRARD INLET	ZONE OF APPLICATION		
Indicator	**Caution (95th percentile +/-20%)**	**Warning (N/A)**	**Trigger (biotic) and supporting guidelines** (geochemical and contaminant)**
Echinoderm abundance*	N/A		
Crustacean abundance	<7		
%*Capitella capitata* complex	>1		>25%
%*Heteromastus filobranchus*	>1		>25%
%bivalves	<30%		<50% reference levels for that year (see Table 2)
Swartz Dominance Index	<4		
Species richness	<39		<50% reference levels for that year (see Table 2)
Bray-Curtis dissimilarity+	>53%		
Axinopsida. serricata %adults with 0/1 stain on shell	Not measured		
Sediment fecal colliforms	>275 MPN		
Mean AVS	>6.6 ug/mol dry wt.		>13.2 ug/mol dry wt.
4-nonylphenol***	R ***(>60 ug/g dry wt ~9% CCME TEU)		>60% CCM Interim guidelines for TEU with TOC=1%;

* Note that Burrard Inlet stations included zero occurrence in many samples
+Note that BC dissimilarity is simply the within-group dissimilarity (95th percentile +20%) for all samples since no reference stations have been identified
** NOTE AVS and 4-nonylphenol levels are not triggers per se, but guidelines in support of liquid waste discharge exposure as causative to biological triggers
*** For outer Burrard Inlet, 4-nonylphenol data are not currently available for sediments, so the reference or background range is theoretical and should be confirmed

4.4.3 Identification of Cause for Warnings or Triggers

For Warning and Trigger situations, it is critical to eliminate natural or region-wide phenomena as the causative factors by:

1. ***Examination of changes to reference ranges in that year i.e., has a caution been reached which will explain the attainment of a warning or trigger level?***
2. ***Assessment of region-wide biotic, geochemical, climatic or oceanographic phenomena using scientific data from Ambient Monitoring Program for southern Georgia Strait (see Appendix G).***

4.5 BENTHIC INDICATORS FOR SMALL STREAMS

4.5.1 The Development of the Benthic Index of Biotic Integrity (B-IBI)

In the 1990s, the Benthic Index of Biotic Integrity (B-IBI) was developed for small streams in the Puget Sound lowlands which have similar habitat and climatic conditions as the Lower Mainland. Indices that measure biological integrity can effectively convey complex biological data in a simple, quantitative (numeric), and qualitative (descriptive) manner. For every site, a single numerical score is calculated based on numerous attributes of the benthic community, and a corresponding description (i.e., excellent, good, fair, poor, very poor) of the health of the indicator community is assigned. The B-IBI has proven very useful as a readily communicated descriptor of stream health. The index is composed of several benthic community attributes or “metrics” that are sensitive to environmental changes (Salmon Web web site, 2002; Karr and Chu, 1997). The B-IBI facilitates comparison of results between study sites and values measured at regional reference sites, or site-specific data collected in previous sampling sessions (i.e., baseline data).

In 1999, a preliminary study was conducted to assess whether the Puget Sound B-IBI method is suitable for use on small streams in the Lower Mainland. The study showed that the method is also suited for assessing stream health in the GVRD. A second study was conducted in 1999 to determine whether effects from stormwater discharges could be identified in large water bodies. This study assessed the effects on sediment quality and the benthic community from stormwater discharges into the North Arm of the Fraser River, however, effects from stormwater discharges could not be distinguished. As a result, in 2003, the Stormwater Interagency Liaison Group and the EMC endorsed the use of the B-IBI methodology as the primary tool for measuring small stream health within the Greater Vancouver area.

The B-IBI is most valuable for assessing change in a stream health rather than as a discrete measure. Therefore, its value in the Integrated Stormwater Management Planning process will increase over time as it will be used to measure changes in stream health as development proceeds and BMPs are implemented. The use of the B-IBI as a measure of small stream health in the Lower Mainland has just begun. A number of questions remain about the variability of B-IBI scores, application of B-IBI and how global factors such as climate change and contaminant transport affect B-IBI. Therefore, it is too early to develop cautions, warnings and/or triggers for effects on small streams using the B-IBI. However, they may be set when these outstanding questions have been addressed and there is continuous multi-year data to develop an appropriate cautions, warnings and triggers assessment methodology.

CHAPTER 5.

HIGHER TROPHIC LEVELS

5.1 INTRODUCTION

5.1.1 Background

As part of a long-term strategy, Environment Canada is in the process of developing Environmental Quality Objectives (EQOs) for the aquatic environment. These are levels of environmental quality or conditions generally considered desirable for receiving environments. As such, EQOs will be, to some extent generic, albeit different environment categories will be recognized, the characteristics and requirements of which will be recognized through the evaluation framework. The vision of this framework is one of healthy aquatic ecosystems, with goals of unimpaired human use and functioning aquatic ecosystems.

Similar visions have been expressed previously within other organizations and various efforts have been made to address these or similar goals, in particular where the organization had or still has responsibility for particular aquatic environments. Thus the development of (Provincial) Water Quality Guidelines and Objectives should be seen as ultimately aiming to achieve the same goals. Therefore, consistency in aims is maintained, if not always entirely in the approaches or methodology.

The category of “unimpaired human use” of water may be subdivided into three components or objectives: drinkable, swimmable and fishable. From the perspective of a functioning or healthy ecosystem, two objectives can be defined: a healthy fish community and a healthy birds/mammal community, with the attendant effects these have on the quality of (aquatic) life forms lower in the food chain.

Water and sediment chemistry are useful components of a monitoring and goal-setting program, in particular where effects of individual chemicals on the various life forms are known. While this may be the case for a number of inorganic elements in certain chemical states, the additive, synergistic and antagonistic effects are certainly not all known in detail and may vary from (biological) species to species. This situation becomes even more complex when we consider the organic chemicals potentially present or discharged into the environment, some natural and some man made. The sheer number of substances, still growing annually, precludes the study of all possible permutations in terms of their combined or separate effects. A number of potentially problematic substances have, however, been identified.

A second problem, particularly in the case of detectable trace organics, is that their local presence per sé does not necessarily appear to have an effect, but their persistence may lead to longer term effects elsewhere. In particular, food chain considerations are important in this respect. For example, trace concentrations of PCBs may not exhibit effects in the local benthic population, but may begin to accumulate progressively up the food chain through grazers, followed by those organisms feeding on grazers etc. and ultimately to fish, birds and mammals. Given that accumulation of the substance through the food chain takes place over an ever-increasing area with every step higher in the food chain, judging local acceptable concentrations in, for example, sediment is extremely difficult.

A further complexity arises in the high variability and potential subtlety of effects. Effects may include reduced lifespan, but also reduced fertility, sex change, enlarged or reduced organs or functional parts, warts and lesions etc. Attributing any or all of these changes to a specific source or even a specific chemical effect is extremely difficult, especially because some of the chemicals that may be contributing to or causing these changes may be undetectable in the concentrations occurring in the aquatic environment.

5.1.2 Monitoring Approaches

Nevertheless, to address the achievement of the goals (unimpaired human use and a healthy, functioning and therefore by definition sustainable aquatic ecosystem), two approaches are possible: a *"bottom up"* or a *"top down"* approach.

The *"bottom up"* approach is characterized by the setting of chemical standards at the lowest level, (i.e. the substrate), at a magnitude that aims to reflect a reduced risk of accumulation or magnification up the food chain. Where chemicals are present in detectable concentrations this may be a useful strategy, especially in a confined environment such as a lake. In such an environment, the standards can be applied to the entire water body, and the potential for accumulation of these substances by higher organisms from other sources is minimized, thus establishing a direct connection between specific source and biota condition. This approach is exemplified in the setting of sediment quality values. However in larger water bodies, such as large lakes, fjords, estuaries and the marine environment, exposure zones are less easily delineated due to the capability of species to migrate in and out of the study area.

In principle, the *"top down"* approach starts at the higher trophic levels, and determines existing and/or acceptable concentrations of certain chemicals in fish, birds or mammals. These levels then cascade down to the prey, taking into account consumption of prey and acceptable levels of the same chemicals in prey. Ultimately and theoretically levels continue to cascade down to a consideration of the lowest level. An organism, or class of organisms, is selected and maximum acceptable values allocated. If these values are exceeded, the expectation is that source control or reduction will ultimately achieve reduction in the selected organism. This forms the basis for "tissue values" (TV) which may be based on wildlife consumption and/or human dietary uptake. Other authors (e.g. Paine 2003) use the initials TRV instead of TV for "Tissue Residue Values"; however, these initials are best avoided as they stand for "Toxicity Reference Values" in environmental (impact) assessment, which is neither the same nor necessarily determined on the same basis.

A multitude of studies and resultant tissue values exist, and different jurisdictions world-wide adopt different TVs where regulatory status is deemed necessary. This document adopts the values determined by Canadian jurisdictions and, in particular, those developed by or for the Province of British Columbia and the Canadian Environmental Guidelines as developed by EC under the mandate of CEPA and CCME. The Canadian Guidelines are those issued in 2002/3 as published in the summary table.

5.2 GUIDELINES AND OBJECTIVES

5.2.1 Tissue Residue Objectives

Tissue residue objectives apply where Water Quality Objectives have been set. Within the GVRD area under consideration, these apply only at the Burrard Inlet and Fraser River. Tissue Quality Objectives are significantly less in number than those for water column and sediment objectives. The currently existing tissue residue objectives are illustrated below in Table 28.

Table 28. Tissue Residue Objectives for Burrard Inlet and Lower Fraser River

Burrard Inlet (Outer Harbour)	**Tissue Objective**
Lead	0.8 microgram/g wet weight maximum in fish flesh (i.e., fish muscle tissue)
Mercury	0.5 microgram/g wet weight maximum in fish flesh
PCBs (the term PCBs applies to the sum of Aroclor 1242, 1254 & 1260 in fish)	0.5 microgram/g wet weight maximum in fish flesh
Lower Fraser River	
PCBs (total)	less than or equal to 0.1 microgram/g wet weight (whole fish)
Chlorophenols (sum of mono-, di-, tri-, tetra-, and penta)	less than or equal to 0.1 microgram/g wet weight (fish muscle)
Dioxins and furans (2,3,7,8-T4TCDD TEQs)	less than or equal to 50 picograms/g (wet weight) in lipids of fish muscle or fish eggs
PAHs benzo(a)pyrene	In Fish Muscle: • less than or equal to 4 micrograms/kg wet weight when consumers eat less than or equal to 50 g/week • less than or equal to 2 micrograms/kg wet weight when consumers eat more than 50 and less than or equal to 100 g/week • less than or equal to 1 micrograms/kg wet weight when consumers eat more than 100 and less than or equal to 200 g/week

Objectives are generally defined for fish, although the Guidelines upon which they are usually based frequently state that they apply to human consumption of edible tissue from fish and/or shellfish. The objectives are set out in various Ministry of Water Land and Air Protection documents either in short form or as a technical guidance document. The technical guidance documents for the Fraser River are available on-line; the Burrard Inlet technical document is not. The technical documents are in-depth reports on surveys and evaluation of results, used in the setting of Objectives values.

Of note: objectives are not proposed for all substances of concern from an (environmental) health point of view. An example of this is Arsenic. In certain waters arsenic is consistently high in fish tissue, due to naturally high background conditions. The purpose of an Objective is to ultimately attain a "normal" background level; due to the naturally high background conditions this objective cannot be achieved. Therefore, an Objective value is not given. The absence of an Objective value therefore does not imply that a substance is not necessarily of concern for human health in dietary consumption. Nor is the attainment of the listed values an indication that the fish in question is fit for human consumption; other unlisted factors may also need to be considered.

5.2.2 Provincial Guidelines and other values

Provincial Guidelines, through Approved Water Quality Guidelines (AWQG) and Working Water Quality Guidelines (WWQG) provide values for tissue residue for a number of substances. These are in the form of maximum allowable concentrations and include human health values for Lead, Mercury, total PAH, total PCBs and Chlorophenols for tainting of fish. Total PCBs has an additional value for wildlife health. The values are illustrated in Table 29, below.

Table 29. Tissue Values based on Provincial Guidelines

Lead	0.8 mg/kg (wet weight) is the alert level for total lead in the edible portions of fish and shellfish for human consumption
Mercury	0.5 mg/kg wet weight maximum in edible portion of fish and shellfish for safe quantity for low consumption on a regular basis of 210 g/week
	0.1 mg/kg wet weight maximum in edible portion of fish and shellfish for safe quantity for heavy consumption on a regular basis of 1050 g/week
PAHs benzo(a)pyrene	Fish and/or shellfish for human consumption of edible tissue • less than or equal to 4 micrograms/kg wet weight when consumers eat less than or equal to 50 g/week • less than or equal to 2 micrograms/kg wet weight when consumers eat more than 50 and less than or equal to 100 g/week • less than or equal to 1 micrograms/kg wet weight when consumers eat more than 100 and less than or equal to 200 g/week
PCBs Total	2 microgram/g wet weight recommended maximum concentration for human consumption (edible tissue)
	0.1 microgram/g wildlife recommended maximum concentration for wildlife consumption (whole fish)

Table 29 illustrates that Guidelines are substantially identical to those in the Objectives, although the actual value adopted in the Objectives may differ.

In addition to the above Guidelines there is a Health Canada maximum allowable concentration of 5 microgram/gram for total DDT

5.2.3 Canadian Environmental Quality Guidelines

The CEQG are developed by Environment Canada under the mandate of CEPA and CCME. An updated summary has recently been published and a summary table can be viewed via the web:

http://www.ccme.ca/assets/pdf/e1_06.pdf

Substances for which tissue concentrations are available are illustrated in Table 30.

Table 30. Tissue Residue Concentrations

CEQG for Tissue Parameters	Tissue Residue
DDD (total DDT = DDD +DDE +DDT)	14.0 micrograms/kg diet wet weight
DDE (total DDT = DDD +DDE +DDT)	14.0 micrograms/kg diet wet weight
DDT (total DDT = DDD +DDE +DDT)	14.0 micrograms/kg diet wet weight
Methylmercury	33.0 micrograms/kg diet wet weight
PCBs Mammalian	0.79 nanogram TEQ/ kg diet wet weight
Avian	2.4 nanograms TEQ/ kg diet wet weight
Dioxins and Furans Mammalian Avian	 0.71 nanogram TEQ/kg diet wet weight 4.75 nanograms TEQ/kg diet wet weight
Toxaphene	6.3 micrograms/kg diet wet weight

Environment Canada (http://www.ec.gc.ca/ceqg-rcqe/English/ceqg/tissue/default.cfm) warns that:

"The Guidelines should not be regarded as blanket values for national protection of wildlife consumers of aquatic biota. Variations in environmental conditions and resident aquatic food organisms and wildlife species across Canada may require guidelines to be modified accordingly".

The Guidelines for tissue residue developed under this framework "are designed mainly for persistent, bioaccumulative, toxic substances that are targeted for virtual elimination from the environment under various provincial, national, and international policies". In this respect, perhaps a somewhat surprising inclusion on this listing is Methylmercury, because the global and atmospheric budget for mercury renders the elimination of this substance highly unlikely. However national and provincial initiatives to eliminate dental mercury waste as a contributor to mercury in the aquatic environment are in place.

The Guidelines are "intended to protect wildlife species that depend on aquatic organisms for food. The (Guidelines) are therefore based on the highest concentration of a chemical in the body tissues of their aquatic food organisms that is not expected to result in adverse effects to them".

Guidelines are therefore not based on "human health" and human dietary uptake, which explains why, for e.g. lead, does not (yet) feature in this listing. Guidelines are under continuing development and further TVs will be issued in future.

5.3 MONITORING PROCESS

5.3.1 Monitoring Tissue Contaminants

Tissue values have been issued for unspecified fish and in some cases shellfish. Therefore, monitoring of the given tissue residues can be through the selection of any fish appropriate to the local environment. Of course it makes sense that, where values are based on human consumption, a food fish is selected, but this is not absolutely necessary.

Some differences are notable between various fish species, depending on their individual modes of feeding. However, guidance can frequently be obtained from historical local surveys which have considered a number of species for which data are available. In this respect the Technical documents accompanying the WQO for the various locations are a rich source of guidance material. Where this guidance is unavailable, commercially valuable species or those fished widely are selected. Migratory species or species roaming over a large area must not be selected; interpreting these results on a local basis would be misleading because the area of interest is, in fact, much larger and less defined.

Surveys of this nature can be very useful in determining the general state of the environment or state of the species itself, such as Harbour Seals or Orcas. However, these types of surveys are often of limited value in determining effects of local discharge or impact. If a species that does not move out of an area of interest can be selected, such as Mummichog in the Atlantic Ocean in Eastern Canada, meaningful conclusions may be drawn. If required, a compromise species may be one that ventures only a limited distance from the area in question, especially if its food supply is more abundant within the study area than outside. An example of such a species is English sole in the Georgia Strait. However, results should still be carefully interpreted, as a degree of uncertainty about where the contamination was collected remains. Patently Salmon species in open (unconfined) environments are not suitable for this type of survey.

Similar considerations apply to shoaling fish such as herring, which may cover a wide area. If the environment at large, or the quality of the stock specifically are the questions of interest, tissue residues may be determined and usefully interpreted. However, these fish are to be avoided in the determination of local discharge effects.

To study the effect of local impacts on local environments, particularly in large water bodies or open waters, fish are generally not the organism of choice due to their tendency to migrate in and out of the area. An attempt to overcome this objection through fish confinement in cages has been implemented, but success has been limited. Moreover, a significant statistical problem arises with the need to quantify "cage effects" in order to submit the results to a statistically rigorous analysis.

Animals more suitable for immobilized study are available in the form of bivalves. Although these animals too can travel, the distance is generally extremely limited. Caged bivalves, in particular Mussels (*Mytilus edulis* or *M. trossulus*), have been employed to determine local impacts on the marine environment in the Pulp and Paper Environmental Effects Monitoring (EEM) Program. Where local circumstances permit, this may be an extremely useful substitute for the fish survey. From a site specific Objective and provincial Guideline perspective, these animals substitute well for fish and their parity with fish is acknowledged in that the established parameters are often for “fish/shellfish”, with identical concentrations for substances in question. The situation is of course slightly different in the case of the Canadian Environmental Quality Guidelines, where the primary objective is not to establish safe concentrations for human health but for other predators.

Although caged or resident bivalves may be employed, a suitable “reference area” will be required or, in the case of a gradient design, upstream and downstream characteristics need to be clearly defined to allow differentiation between effects on the health of the animal caused by the discharge under study and those caused by other influences. In the case of a substantially well mixed environment with a multitude of other confounding factors, such as Burrard Inlet, clear identification of a reference area may be a significant problem. Although caged bivalves may be used to determine the nature and source of discharges causing gross effects, more subtle effects and their sources may be more difficult to determine. Tissue residues, generally due to longer term exposure in these animals, fall under the latter category. Furthermore, the feeding and food selection mechanisms are different from those of predatory fish; therefore, results yielded by bivalve surveys may illustrate little or nothing regarding tissue residues in higher animals, unless these higher animals feed extensively on mussels. Significant progress in the use of caged bivalves for determining and tracing effects is being made, but further work is required.

Due to various uncertainties, including location specifics of where tissue contamination was acquired, tissue residue values, whether Objectives or Guidelines, cannot be allocated a “warning” or “trigger” status within the LWMP process; unequivocal linkage between tissue concentrations and specific discharges cannot be established. However, the information is valuable and potentially useful in combination with other factors. Acknowledging the importance of tissue residue concentrations in establishing the health of animals further up in the food chain, tissue residue values are allocated “cautionary” status and will therefore undergo monitoring where appropriate and feasible. For a further in-depth discussion on tissue residue values and their interpretation, a report by Paine (2003) is appended (Appendix B).

5.4 MONITORING AREAS

5.4.1 Burrard Inlet / Lions Gate

Water Quality Objectives for tissue apply to Burrard Inlet/Lions Gate. However, the nature of this area does not lend itself well to a fish survey because populations are highly migratory and the area is characterized by a multitude of confounding influences. To date, the delineation of a clear zone of influence due to the Lions Gate WWTP has been impossible; therefore, a gradient design for monitoring is unsuitable. TVs obtained from a fish survey will be difficult to interpret and treat in a scientifically and statistically rigorous manner.

Studying tissue residues in Dungeness Crab as a comparison between the Inner and Outer Harbour may be useful, in particular with respect to PAH, but until the in-depth study for the Inner Harbour has been completed the utility of such a study cannot be fully determined.
The current joint GVRD/NWRI Mussel study program lends itself to the inclusion of tissue residues as a parameter in selected locations. This program is based on the local study of caged bivalves in various locations in Burrard Inlet, combined with a study on the health of intertidal resident Mussel populations. The resident populations studied are at Stanley Park (2^{nd}/ 3^{rd} Beach), Jericho (off Jericho Yacht Club) and a location close to West Vancouver Laboratories (DFO).

It is proposed that Mussels from these locations, including the caged bivalves, could be taken and analyzed for tissue residues in accordance with the applicable Objectives for the Burrard Inlet Outer Harbour.

The parameters are:

- Lead
- Mercury
- PCB total

In addition, the Provincial Guidelines have been considered.

Chlorophenols are not a likely substance to be encountered in significant quantities and in any case associated with "tainting of fish tissue" rather than environmental health. Chlorophenols are an Objective in the Inner Harbour, but were not considered applicable to the Outer Harbour in the setting of Objectives. Should Chlorophenols be encountered in the Outer Harbour, Inner Harbour is likely the source in the first instance. Therefore, the exclusion of analysis for Chlorophenols in the Outer Harbour is proposed until such time as the Inner Harbour study has been completed. The inclusion Chlorophenols for tissue monitoring will then be re-evaluated.

PAH in tissue are usually highly variable due to their rapid metabolism. Therefore, in order to analyze for the presence of PAH in the environment their metabolites must be included. Little is known regarding PAH metabolic activity in Mussels and therefore the analysis would currently be inconclusive. The analysis of PAH and their metabolites in Dungeness crab is proposed once the Inner Harbour study has been completed. This will then allow both quantification of PAH in Crab tissue as well as facilitate comparison with the Inner Harbour, which is suspected to be a substantial source of these materials.

DDT/DDD/DDE are not expected to be a major issue in the Outer Harbour and it is therefore analysis is not proposed at this time.

Analysis for Toxaphene, the only parameter included in the Canadian Quality Guidelines and not in any of the Provincial criteria, will be investigated for feasibility, and if so, carried out at least once as this potential contaminant may be relevant. In addition, in the area identified as Station 1, subject to a special investigation, Mussel tissue if present, will be analyzed for the identical substances and be reported in the specific study report.

5.4.2 Iona Area

Provincial Objectives do not apply in the receiving environment of the Iona discharge. However, the Provincial Guideline criteria are substantially the same and, with the exception of chlorophenols, will be adopted for analysis in fish tissue (English sole) as per the previous (2001) survey following review of the Iona monitoring program and its cycle, due in 2004. Chlorophenols are extremely unlikely to be present in any substantial quantity.

DDT has been identified in Iona sediment but in small quantities. Previous surveys have not shown a problem with DDT, and as the substance is no longer produced or manufactured for use in this area, it represents a historical problem of decreasing magnitude.

There is at present no reason to assume that Toxaphene will be significantly present in fish tissue in the Iona area. If, however, it significant presence is identified at Burrard Inlet, this compound will be assessed in the Iona area.

The Iona program has historically analyzed a substantially greater number of parameters. This document, as explained above, focuses on the relevant Objectives and Guidelines. Other information collected in this monitoring program is mentioned in the final section “Other studies and studies by others”

5.4.3 Lower Fraser River

At present, extensive efforts are being undertaken to characterize the Fraser River ambient environment. This includes a very substantial fish tissue component consisting of Peamouth chub in ambient areas. Peamouth chub was identified in a consultant’s report as a suitable species and there have been previous studies using this fish in the Fraser River.

Following the completion of this survey, the feasibility of using Peamouth chub as the sentinel species for the Lower Fraser and the areas potentially under the influence of discharges will be evaluated, including calculation of and analysis of the fish tissue residual concentrations. At that time the appropriate suite of analytes will be determined. However, these will include the criteria set as Objectives for those relevant parts of the Fraser.

The survey is expected to reach completion at the end of 2004, and fish tissue criteria will be assessed in the 2005 season in discussion with the Environmental Monitoring Committee (EMC).

5.5 CONCLUSION

5.5.1 Other Studies – GVRD and External

The preceding sections illustrate that the Objectives and Guidelines represent a limited subset of all chemical constituents potentially present in an aquatic environment. Large numbers of other criteria which might be of environmental relevance are in existence, but are not addressed above. These can include parameters of direct relevance to individual species, to the use of individual species (e.g. for consumption), to the environment at large and to specific issues, some of which have not yet arisen.

A variety of studies are taking place on a continual basis in the waters of specific interest to the GVRD as well as in the broader environment. Some of these may be private initiatives, with others sponsored by Government or Academic bodies. All of these studies contribute to our understanding of the nature of the environment and potentially contribute to our efforts to achieve a sustainable environment.

Some of these studies will, inevitably, highlight new or different areas of concern, not all of which can be anticipated at this stage and therefore recognized in the formalized structure of the "cautions, warnings and triggers" process or those actions potentially instigated by the process.

However, these studies contribute valuable information, which may instigate or direct future action. Therefore, these studies require consideration within the broader framework of the "cautions, warnings and triggers" process. The adaptive and dynamic nature of the process provides the flexibility required for the introduction of new and relevant information or monitor other information and factors not yet at a stage for direct use in environmental management, but nevertheless critical for inclusion in our consideration of management actions.

An example of such a program is the current MWLAP sponsored program regarding PCBs in Harbour seals in the Georgia Strait and Puget Sound, carried out under the direction of Dr Peter Ross (IOS). Our environment includes Harbour seals and Orcas, and we are aware, through public and scientific communication, of the serious concerns that surround PCB content in these animals and the effects posed on their populations. The GVRD program does not include analysis of PCBs or other substances in Orcas and seals, but the importance of this issue is nevertheless acknowledged. Additionally, a study carried out by McDonald at IOS, sponsored by the GVRD under the Georgia Strait Ambient Program, is considering the effect of global budgets of contaminants such as PCBs on the Georgia Strait. These studies may well provide future guidance in the best manner with which to manage the PCB issue. Therefore, both 'external" and other GVRD programs such as the Ambient Programs and Endocrine Disruptive Compound Program provide critical supportive information. Much of the information not currently highlighted in this document but already being collected by the GVRD for various reasons also falls under this category. For example, the metals in tissue not required under the Objectives or Guidelines, but nevertheless of importance in the discussion of ambient conditions and natural variability and cycles, are included in these supplemental data.

This supportive information also serves to highlight new studies and issues for discussion, following which a new program could be initiated or efforts could be directed in the observation or sponsorship of external studies. The EMC, in its technical advisory capacity, has a critical role in this process; it can introduce, highlight and discuss new research or issues and ultimately advise the GVRD to undertake certain studies or actions. The EMC, through the collective and individual expertise of its members, plays a critical role the process as a whole.

CHAPTER 6.

SUMMARY AND CONCLUSIONS

6.1 OVERVIEW

The environmental cautions, warnings and triggers framework discussed in this document forms the foundation of a dynamic process for assessing risk from GVRD liquid waste discharges on the health of the receiving environment. The application of the cautions, warnings and triggers process will help to identify if and where GVRD discharges are contributing to environmental risk and could ultimately facilitate the implementation of timely mitigating action in accordance with the predictive nature of the indicator levels selected. Approved mitigation plans would ensure the prevention of adverse changes prior to the occurrence of unacceptable biotic or habitat degradation.

The cautions, warnings and triggers approach has been applied to each of three primary compartments of the aquatic environment including the water column (Chapter 2), sediment (Chapter 3) and biota (Chapters 4 – benthos, and Chapter 5 - tissue). A summation is provided below.

6.2 SUMMARY

6.2.1 Water Column

Background

This chapter outlined the application of the process to the water column with due regard for the relevant Water Quality Guidelines and Objectives. The process provides information to effectively manage liquid waste discharges on a regional basis, and furnishes a scientific foundation upon which to set priorities and to determine appropriate and effective mitigation.

Provincial Water Quality Guidelines (PWQG) apply throughout the Province and provide benchmarks for the assessment of water quality, as well as sediment and tissue residue quality. Site-specific Water Quality Objectives (WQO) are derived from the PWQG and incorporate local water quality, water uses, water movement, waste discharges and socio-economic factors of the given water body. However, neither the PWQG nor WQO consider local environmental conditions; therefore, natural conditions may potentially exceed both guidelines and objectives. Commitment C1 of the GVRD’s Liquid Waste Management Plan (LWMP) outlines a collaborative process for developing new or revised WQO for water bodies within the GVRD. These guidelines and objectives do not apply in the initial dilution zones (IDZs) of municipal effluents.

A water column evaluation model has been developed to assess achievement of caution, warning or trigger levels in the receiving environment at the IDZ boundary of the WWTP and potentially CSO discharges. The evaluation model can be used to compare maximum and average initial dilution zone (IDZ) boundary concentrations with maximum and average PWQG and WQO, respectively. However, only instantaneous minimum dilutions have been determined for the

CSOs; therefore, only maximum IDZ boundary concentrations can be calculated and compared with relevant maximum PWQG and WQO.

WQO model input data include estimated dilution values at the IDZ boundary of each WWTP and CSO discharge, ambient constituent concentrations in the receiving environment near each WWTP and CSO discharge and estimated constituent concentrations for each WWTP and CSO discharge.

Development of Indicators

Indicators for assessing water column constituent concentrations relative to the caution, warning and trigger levels are either full or partial, depending on how they meet established criteria. Full indicators meet all criteria, and have been determined for the Fraser River ambient environment, for all 5 GVRD WWTPs and for 8 of the 14 GVRD CSO locations. By definition, partial indicators are substances that are monitored in the effluent but have no applicable ambient data, or have analytical detection limits lower than either the maximum or average PWQG, but not both.

Indicator substances that will be used to assess caution, warning and trigger levels in the water column of the receiving environment are illustrated in Table 31, below.

Table 31. Water Column Indicators

Discharge	Full Indicators	Partial Indicators
Iona Island WWTP	Arsenic, Cadmium, Copper, Lead, Mercury	Total Aluminum, Barium, Boron, Iron, Manganese, Molybdenum, Nickel, Selenium, Silver, Ammonia, Nitrate, Nitrite, Phenols, Suspended Solids, Beryllium, Vanadium, Chlorobenzenes, PAHs
Lions Gate WWTP	Fecal Coliforms (May 1 – Sept 30), Copper, Lead, Mercury, Zinc, Nickel	Iron, Dissolved and total Aluminum, Arsenic, Barium, Boron, Cadmium, Molybdenum, Selenium, Silver, Ammonia, Phenols, Nitrate/Nitrite, Beryllium, Vanadium, Chlorobenzenes, PAHs
Annacis Island WWTP	Fecal Coliforms (Apr 1 – Oct 31), Suspended Solids, Ammonia, Copper, Lead, Manganese, Zinc, Total Aluminum, Arsenic, Barium, Boron, Cobalt, Iron, Molybdenum, Nickel, Selenium, Antimony, Beryllium, Lithium, Thallium, Vanadium,	Dissolved Aluminum, Cadmium, Cyanide, Mercury, Silver, Phenols, Nitrate/Nitrite, PAHs Organochlorine Pesticides, Chlorobenzenes

Table 31 continued

Discharge	Full Indicators	Partial Indicators
Lulu Island WWTP	Fecal Coliform (Apr 1 – Oct 31). Suspended Solids, Ammonia, Copper, Lead, Manganese, Zinc, Cobalt, Iron, Nickel, Silver	Total and dissolved Aluminum, Barium, Boron, Cadmium, Mercury, Molybdenum, Nitrate/Nitrite, Phenols, Sulphate
NW Langley WWTP	Fecal Coliform (Apr 1 – Oct. 31), Suspended Solids, Ammonia, Arsenic, Copper, Lead, Manganese, Zinc, Cobalt, Iron, Nickel, Silver, Nitrate	Total and dissolved Aluminum, Barium, Boron, Mercury, Molybdenum, Phenols, Sulphate
English Bay/Alma Discovery, and Balaclava CSOs	Ammonia, Cadmium, Copper, Lead, Mercury, Nickel, Zinc	Suspended Solids, Arsenic, Barium, Iron, PAHs
Manitoba, Angus, Borden, South Hill, MacDonald, and Glenbrook CSOs	Ammonia, Suspended Solids, Arsenic, Cadmium, Copper, Iron, Lead, Mercury, Nickel, Zinc	Barium, Mercury, PAHs
Heather, Brockton, Cassiar, Clark, Westridge, and Willingdon CSOs	n/a	Suspended Solids, Ammonia, Arsenic, Barium, Cadmium, Copper, Iron, Lead, Mercury, Nickel, Zinc, PAHs

Caution, Warning and Trigger Levels

Water column cautions are proposed based on calculated indicator substance levels at the IDZ boundary or measured indicator substance levels in the ambient receiving environment relative to the PWQG. The proposed water column Caution level is:

- Calculated constituent concentration outside the Initial Dilution Zone is greater than or equal to 60% of the relevant Provincial Water Quality Guideline value.

WQO Warnings are proposed based on calculated indicator substance levels at the IDZ boundary relative to site-specific WQO. The proposed water column Warning Level is:

- Calculated constituent concentration at the Initial Dilution Zone boundary is greater than or equal to 60% of the relevant Provincial Water Quality Guideline value.

Triggers are proposed based on measured indicator substance levels at the IDZ boundary relative to WQO. The proposed water column Trigger Level is:

- Measured constituent concentration at the Initial Dilution Zone boundary is greater than or equal to 80% of the Water Quality Objective value.

Responses

Based on model results, some indicator substances currently exceed caution and/or warning levels at GVRD WWTPs and/or CSOs. In all cases, a response has been initiated in accordance with caution, warning and trigger responses outlined in this document. In some cases, investigations have revealed naturally elevated background levels of substances having excursions. In others, studies have been undertaken to accurately identify the source(s). Through the LWMP, the GVRD and member municipalities have committed to continuous improvements in the sewerage system and ultimate elimination of CSOs. Caution, warning and trigger responses help to ensure prompt mitigation where required, so that environmental degradation is avoided.

6.2.2 Sediment

Guidelines and Objectives for Sediment

WQO include values for substances in sediments whereas AWQG are predominantly associated with substances in the water column and values for only two substances are available for sediment. WWQG apply to a significantly greater number of substances in sediment, but these values have not yet been assessed as to their applicability and suitability for adoption as Approved Water Quality Guidelines. Guideline values cannot be adopted automatically as "target values" for sediment at a given location. Where sediment quality values are introduced as a means of monitoring discharges or the effects of anthropogenic substances on an environment, consideration must first be given to the existing conditions and any effects must be placed within the context of the ambient environment. Therefore, any adoption of a set of values requires a thorough in situ assessment and understanding of the existing biotic conditions of both the ambient and target environments.

Unlike water column factors, sediment contributors, present as particulate matter or dissolved matter, do not necessarily follow the same path as the effluent plume and must therefore be considered separately from water column dissipation. Sediment quality monitoring associated with discharges requires intimate knowledge of the ultimate area of deposition and also requires fate and effect studies of both the target constituents and other sediment loads, which must then be put in the context of the ambient environment.

Once confounding factors have been eliminated, benthic surveys may distinguish differences between areas, which can be used in the partitioning of zones; results from benthic surveys are then correlated with sediment chemistry.

Methodology

The purpose of monitoring sediment quality is to determine whether, or to what extent effluents might affect local sediment quality, to determine whether Guidelines or Objectives are exceeded (and whether the exceedance has been caused by effluent discharges) and to establish correlations, if they exist, between sediment quality and the condition of biota. To maintain the linkage between sediment and biota components, sediment chemistry is performed on sediments retrieved from the same area as the benthic grab.

The simplest study design is the "Single Gradient Design", suitable for locations where the effluent path is well known and where effects can be monitored to show a decrease relative to increasing distance from the origin. This model functions well for effluents in the water column. However, sediment deposition characteristics are unique, and series of zones with individual characteristics can often be identified. While the "Gradient Design" is appropriate for the Iona discharge, where a clearly influenced and uniquely identifiable zone is detectable, a "Radiating Design" is adopted at Lions Gate/Burrard Inlet where this is not the case.

Parameter Selection

Unlike Iona, results for sediment in the Lions Gate receiving environment illustrate that all components at some point or time may be present in quantities greater than the Objectives. Exceedances are fragmented and highly localized either in space or time and appear to originate from different sources. No areas of significant localized solids deposition have been identified in the Outer Harbour. Nevertheless, sediment quality parameters mirroring the WQO list for sediment parameters will be routinely monitored for at the corresponding benthic stations. (See Table 15, Chapter 3). Additionally, a number of other parameters are being monitored, including AVS, fecal coliform, 4-NP and coprostanol.

No WQO have been set for the Iona receiving environment. Monitoring of the current routine suite will continue based on the WWQG, subject to program review; however, all information obtained will be allocated a "cautionary" status in the "cautions, warnings and triggers" framework.

Extensive efforts by the GVRD to determine the ambient conditions in the Lower Fraser River are ongoing. However, sediment deposition and movement patterns in the Lower Fraser River are extremely complex and variable. A multitude of confounding factors, including CSOs, storm water overflows, industrial discharges and land drainage exist. However, Fraser River sediment quality will be monitored with regard for the WQO relevant to those sections of the Fraser River.

Data Interpretation

Current data show some variation in individual parameters, but do not exhibit uniform variation for all parameters in any given sampling period. Results may be from highly transient events making direct comparison misleading. Some correlation between the parameters or some effect on the biota would have to be identified before these could be attributed to the Lions Gate discharge. Paine (2003) proposed a method of using Hazard Quotients (HQ), and developed a Sediment Quality Index (SQI). The HQ is calculated by dividing the concentration of the substance by the PEL or Guideline/Objective value. The SQI, derived by taking the mean of the HQs, functions as a means of detecting and tracking change. PEL-based indices provide a more relevant assessment of potential biological effects whereas indices based on Guidelines or Objectives provide a means of assessing overall sediment quality relative to these target values. Either or both can be adopted as cautions (Guidelines) or warnings (Objectives) based on statistical trends where appropriate. Indices can then be used in the monitoring of trends. The number of parameters and the parameters themselves must undergo careful selection to ensure that the ability of the index to detect and track change is maintained. Substances which are naturally present in high concentrations (particularly when concentrations exceed the PEL) should be excluded from calculations involving PEL. Therefore, Copper, Nickel and Arsenic, all identified at naturally high levels in the Georgia Strait and Burrard Inlet, are excluded from the index.

Adoption of Cadmium, Chromium, Lead, Mercury, Silver and Zinc has been proposed as a suitable suite for an index for calculations against both PEL-based indices and WWQG or Objectives.

Although collection of trace organic data will continue at both the Iona and Lions Gate/Burrard Inlet receiving environments, the inclusion of trace organic data in the calculation of indices is not currently proposed. A method is actively being sought to integrate the results of both inorganic and organic parameters into a single statistic which can be used for monitoring change and can provide some indication of the likely effect of the combined substances. In the interim, the metal indices and trace organic data will be handled separately.

Response – Iona

Because no applicable WQO exist in the Iona receiving environment, WWQG and appropriate AWQG are adopted for the Iona area as "cautionary". Proposed SQI values are calculated annually both using PEL and using the WWQG/AWQG. Annual values are compared to the "limit value"; where the limit value is exceeded either on one or multiple stations, the individual Hazard Quotients are analyzed and the substance(s) causing the increase identified. No further immediate steps are taken unless obvious and substantial discharge-related factors exist and changes in biota are evident. If a subsequent year's sampling identifies a further or sustained increase, an investigation will be undertaken. If information acquired coincides with a change in biota, as described in Chapter 4, action will be taken consistent with the cautions, warnings and triggers framework. Organic analyses will continue, trends will be characterized and monitored in order to establish a rigorous methodology for integrating these with other analytical results.

Collection of data for other parameters (coprostanol, 4-NP, TOC and AVS) will continue as these are required in the interpretation of the benthic results.

Response – Burrard Inlet / Lions Gate

Unlike the Iona receiving environment, Water Quality Objectives apply to the Burrard Inlet. The Lions Gate WWTP discharges into the Outer Harbour and it has been designated accordingly in the Water Quality Objectives for Burrard Inlet; therefore, the sediment monitoring program concentrates on the Outer Harbour.

The Lions Gate receiving environment monitoring program is more recently established relative to the mature Iona Program. Recent surveys have yielded no evidence of Lions Gate solids deposition and while some chemical analyses have been performed, trace organics data have not been collected to date. Metal concentrations are highly variable and to some extent localized. At present, insufficient data are available for the determination of "limit values" as established at Iona. Sediment quality data collected for Burrard Inlet and Lions Gate will function as "warnings" rather than "cautions" using the SQI approach because WQO rather than WWQG apply to the Outer Harbour.

If an identified substance(s) is (are) found to be potentially directly attributable to the Lions Gate discharge, increased sampling and analysis would be initiated over a suggested five-week period. If the extended program identifies a further or sustained increase in the SQI values compared to the applicable limit values, an investigation of cause would proceed. If the discharge is identified as the cause, trends and potential mitigating actions would be identified and evaluated consistent with the LWMP process. Action would be taken if a change in sediment quality were to coincide with a change in biota as described in Chapter 4, or were to suggest likely change towards warning or trigger status in the near future and if Lions Gate or another specific GVRD discharge were identified as being the source.

Collection of data for other parameters (coprostanol, 4-NP, TOC, AVS) will continue, and analytical results for trace organics will be integrated. Other studies in the area, including the GVRD/NWRI mussel program, will also be considered for potential use in the identification of cause and effect.

6.2.3 Benthos

Background

GVRD's caution, warning and trigger framework has been developed as a means of assessing the risk from municipal discharges to health of the receiving environment. Sessile organisms inhabiting marine sediments primarily settle as juveniles, and live out their entire lives within a very small radius of their original settlement location, thereby providing a direct target for settlement of particulate matter from liquid waste discharges. Over time, these organisms must tolerate whatever happens to settle in their habitable space and may therefore provide valuable indicators of environmental change. For this reason, benthic biota are the only indicators that integrate the exposure, long-term, chronic and acute effects of settling effluent constituents from wastewater discharges. The framework for benthic indicators, cautions, warnings and triggers is ultimately designed to protect the health of those organisms that must live, grow, reproduce and feed higher trophic levels in the receiving environment.

Developing a Triggers Framework

In order to be useful as tools to help determine how the receiving environment is assimilating and being affected by effluent discharges from the marine wastewater outfalls, some well-conceived constraints must be placed on the character and extent of effects of concern in the receiving environment. Effects of concern are those which are ecologically significant to the ambient biotic community and/or potentially hazardous to higher trophic level (including human) health.

Existing benthic guidelines and indicators used in other jurisdictions (primarily North America) were assessed to determine respective success, and applicability to the particular receiving water environments of the GVRD marine discharges. Most of the environmental research and monitoring literature is focused on the issue of input and effects of "contaminants", primarily chemical. Unfortunately, there is a lack of clear and convincing evidence related to the in-situ effects of contaminants on biota in the receiving environment. Few generic ecosystem-based (receiving environment) biotic guidelines for regulatory purposes exist. Because of confounding influences at site-specific locations, local receiving environment health is best addressed through relevant ambient and discharge monitoring programs.

To characterize the triggers and warnings framework for a wastewater discharge, the pertinent questions may be clearly stated as:

1. *Can the zone of influence of the discharge be measured and tracked spatially and temporally?*

2. *Are there biotic effects within the zone of influence?*
3. *Can these biotic effects be confidently associated with the discharge?*
4. *What factor(s) cause these biotic effects?*
5. *Are the effects of ecological importance now or in the future?*
6. *How do we respond to ecologically important effects?*

Criteria important in the determination of indicator levels include statistical variability, existing guidelines, toxicity data, scientific literature and ecological and physical characteristics of the environment in question.

Effects in the Iona Receiving Environment

The annual Iona receiving environment monitoring program has been very successful at showing the magnitude, extent and temporal stability of benthic and sediment contaminant distributions related to the Iona discharge. Zones of impact have been derived statistically from monitoring data for 2000 to 2003. Sampling stations are sorted into “moderately impacted”, “less impacted”, “background (or reference)” and “confounded” for the purposes of long-term assessment of change. Benthic conditions appear to have remained stable in the Iona receiving environment between 2000 and 2003. No “gross” impact areas were identified; serious defaunation and decline in species richness were not noted at any station. A detailed assessment of the ecological significance of the discharge effects in the Iona receiving environment is included as Appendix D.

Sediment geochemistry changes are primarily responsible for benthic invertebrate effects around the Iona discharge. Of most concern at Iona is the moderately affected area within 1 km N of the outfall between about 60-90m depth. Within 3 km N of the Iona outfall, a modest decline in species richness and a loss of ophiuroids and crustacean fauna occurs. Sediment geochemistry indicates maximum AVS values, and thus maximum reduction in near-surface sediment oxygenation. However, there is no concurrent biomass decline, and the fauna retains both large and small members as well as reasonable levels of juvenile recruitment. This affected zone is of concern, but the situation is spatially limited and temporally stable and there is currently no evidence to indicate related higher trophic level or long-term, irreversible effects.

Effects in the Lions Gate Receiving Environment

A monitoring program based on the same protocols as those used for the contemporary IONA monitoring program was initiated in September of 2002, and repeated in March of 2003. Similar benthic monitoring surveys were carried out for some outer Burrard Inlet stations by Environment Canada in 1987, 1989 and 1995 (Burd and Brinkhurst 1990, Cross and Brinkhurst 1991, Burd 1992, Boyd et al. 1998), although the sampling methodology was different from that used in the GVRD monitoring program. Some of this historical data may be of value for assessing long-term condition of the outer Burrard inlet benthos.

The same ecological ramifications as noted for Iona above are important for the benthic fauna and higher trophic levels in the Lions Gate receiving environment. No clear detrimental effects on benthic fauna have been noted to date in outer Burrard Inlet. No evidence of notable enrichment in the form of enhanced abundance of known opportunists has been identified. Therefore, it cannot be concluded that there are any effects of concern to the benthos related to the Lions Gate discharge in this area. However, with one pre- and one post-freshet survey completed, there is currently insufficient information to make any conclusions with confidence. As in the case of Iona, the weight of evidence will build with each additional year of data.

Indicator Selection and Zone of Application

Criteria important in the selection of indicators include statistical variability, existing guidelines, toxicity data, scientific literature and ecological and physical characteristics of the environment in question.

Based on results of the Iona 2000-2003 receiving environment monitoring programs and results of research and discussion documents prepared for the GVRD, a number of potential exposure, warning and trigger indicators have been identified for the discharge receiving environments. These are primarily macrobiotic (benthos) indicators. However, sediment geo-chemistry and discharge-specific indicators are necessary to support and interpret biotic changes. Since sediment organic enrichment and related geochemical changes have been suggested to cause most of the observed biotic effects, warning and trigger levels should be based on biotic indicators coupled with reliable geochemical indicators. There is also potential that sources of organic enrichment other than wastewater discharges may occur in the outfall receiving environments (particularly true for outer Burrard Inlet). Therefore, any geochemical and biotic indicators used for warnings and triggers must be linked with a concurrent wastewater-specific indicator for the discharges such as 4-nonylphenol, which is considered an excellent indicator of wastewater.

The confounding influences in the Lions Gate receiving environment are extensive. Due to the limited data available for outer Burrard Inlet to date, a similar suite of indicators as designed for Iona has been suggested for outer Burrard Inlet, but further monitoring may provide additional indicators.

Cautions, Warnings and Trigger levels

In order to confirm that biotic caution, warning and trigger levels are related to the discharge effluent, they must be reached concurrent with notable increases in both a geochemical indicator of sediment enrichment (AVS) and a reliable sediment contaminant indicator of wastewater exposure (4-nonylphenol).

Statistical criteria are used to set caution and warning levels for the discharges. Caution levels apply when any new reference samples fall outside +/-20% of existing reference ranges. Biotic and geochemical warnings apply only to affected zones. Changes resulting in warnings are not known to be ecologically detrimental, but may ultimately lead to detrimental effects if the direction and rate of change continue. Warnings therefore provide a means of preventing and/or reversing conditions which have resulted in the attainment of a warning level. Warning levels would be reached in impoverished and biotically enriched zones at Iona when any three replicate samples fall outside the 95th percentile range (+/-20%) for that zone for two sampling years. However, warning levels for affected zones do not apply in outer Burrard Inlet since no clear “effect” zones that can be attributed to the Lions Gate discharge have been identified.

Non-statistical criteria are used to determine trigger levels because triggers represent a change of sufficient magnitude that it may cause imminent adverse biotic effects. This is not a statistical judgment, and must be determined based on best professional judgment, on international research and experience in other jurisdictions, and on available information concerning the nature and consequences of extensive organic enrichment effects in marine habitats.

Trigger levels are reached following change from historical condition, past warning levels, to +/- 50% of reference ranges (based on 95th percentile for a given year) in any three replicate samples over two sampling years. Triggers include change in proportion of bivalves concurrent with significant increase in AVS and 4-nonylphenol, change in species richness concurrent with significant increase in AVS and 4-nonylphenol or an increase in either *C. capitata* or *H. filobranchus* to 25% of total fauna concurrent with significant increase in AVS and 4-nonylphenol. In biotically enriched zones only, a trigger event may be indicated by a loss of all echinoderms and crustaceans concurrent with significant increase in AVS and 4-nonylphenol.

A similar indicators, cautions, warnings and triggers combination as designed for the Iona receiving environment has been suggested for outer Burrard Inlet. No reference stations and therefore reference ranges have been determined to date in the outer Burrard Inlet monitoring program. Caution levels for outer Burrard Inlet are therefore considered interim due to insufficient monitoring data to determine temporal variability.

Response to Cautions, Warnings and Triggers

The exceedance of a caution level implies that the reference range for the indicator(s) in question must be re-examined. If a specific anthropogenic or natural event can be attributed to the change, then a decision will be made as to whether the location is still suitable for reference information, and if so, how the reference ranges should be modified. In some cases, the change may be region-wide. It is understood that cyclical or climate-related biotic “events” can occur, and should not be confused with discharge-related effects. If the change can be related to the discharge, effect zones will be shifted, and relevant warning and trigger levels within the new “zone” boundaries will come into effect.

GVRD’s response to a warning event will include intensified sampling to confirm cause, predict progression towards trigger status and assess means of mitigating the observed trend. Unlike a warning event, a trigger event clearly implies that an unacceptable environmental impact will likely occur, and will therefore result in action. Following a trigger event, if the discharge is identified as the cause, a mitigation plan will be reviewed with the Environmental Monitoring Committee, confirmed with the GVRD and presented to the Province for approval leading to implementation and reversal of adverse changes before unacceptable biotic or habitat degradation occurs.

The elimination of natural or region-wide phenomena as the causative factors of caution, warning and trigger situations is critical. This is accomplished through examination of changes to reference ranges in that given year coupled with assessment of region-wide biotic, geochemical, climatic and oceanographic phenomena using scientific data from the Ambient Monitoring Program for southern Georgia Strait.

Benthic Indicators for Small Streams

Currently, a benthic monitoring approach called the Benthic Index of Biotic Integrity is being assessed as a potentially useful descriptor of small stream health within the GVRD.

6.2.4 Higher Trophic Levels

Background

As part of a long-term strategy, Environment Canada is in the process of developing Environmental Quality Objectives for the aquatic environment, a framework built upon the goals of protecting aquatic ecosystem health, function and sustainability and of ensuring unimpaired human use. The development of (Provincial) Water Quality Guidelines and site specific Objectives ultimately aims to achieve those same goals. Overall ecosystem health is partly dictated by two critical components: the health of the fish community and the health of the birds/mammal communities.

While a number of inorganic elements and organic and inorganic substances have known effects on given life forms, the additive, synergistic and antagonistic effects are not always known in sufficient detail and effects may vary significantly from biological species to species. Furthermore, local presence of a given substance may not appear to have an effect, but its persistence may lead to future longer term effects over a much wider area through successive bioaccumulation up the food chain. Determining locally acceptable concentrations of a given substance is therefore extremely complex.

Possible Approaches

The “bottom up” approach is characterized by the setting of chemical standards at the substrate level at a magnitude that aims to reflect a reduced risk of accumulation or magnification up the food chain. In confined environments where chemicals are present in detectable concentrations, this approach may be useful. The “top down” approach begins at higher trophic levels and determines existing and/or acceptable concentrations of certain chemicals in fish, birds or mammals, including humans. Ultimately, these levels cascade down to some lower level where an organism or class of organisms is selected and maximum acceptable values attributed. This approach forms the basis for “tissue values”.

Guidelines and Objectives

Tissue residue objectives apply where site specific WQO have been set and are generally defined for fish although the Guidelines upon which they are based frequently state that they apply to human consumption of edible tissue from fish and/or shellfish. Provincial Guidelines, through AWQG and WWQG, provide values for tissue residue for a number of substances in the form of maximum allowable concentrations, including human health values. Guidelines for tissue residue developed under the Canadian Environmental Quality Guidelines (CEQG) are designed primarily for persistent, bioaccumulative, toxic substances that are targeted for virtual elimination from the environment. These Guidelines are intended to protect wildlife species that depend on aquatic organisms for food.

Monitoring

Where values are based on human consumption, monitoring a food fish inherently makes sense. However, fish are not necessarily the organism of choice in a study of the effect of impacts on local environments due to their tendency to migrate in and out of the area in question. However, a fish species that ventures a limited distance from the area in question would be preferable to one that undergoes more lengthy migrations. A potentially useful substitute for the fish survey may be the monitoring of bivalves, since they are a resident species with limited movements.

Due to highly migratory fish populations and multiple confounding influences at Burrard Inlet/Lions Gate, a fish survey to determine effects caused by the Lions gate discharge or any other specific discharge exclusively, may not be sufficiently informative. However, studying tissue residues in Dungeness crab with respect to PAH may be useful. The current joint GVRD/NWRI Mussel program lends itself to the inclusion of tissue residues as a parameter in selected locations. Criteria selected are the Provincial Water Quality Guidelines, the Provincial Approved and Working Water Quality Guidelines and the Canadian Environmental Quality Objectives, with some reservations.

Water Quality Objectives do not apply to the Iona discharge area. However, the various Provincial Guideline criteria are substantially identical and are adopted for analysis of fish tissue (English sole) with some reservations. DDT has been identified in Iona sediment, but in small quantities, and likely represents a historical issue of decreasing magnitude. If a significant presence of Toxaphene is identified at Burrard Inlet, it will also be assessed at Iona.

Extensive efforts are being undertaken to characterize the Fraser River ambient environment, including an extensive fish tissue component. The feasibility of using Peamouth chub as the sentinel species for the Lower Fraser is being evaluated.

Response

Due to various uncertainties, including location specifics of where tissue contamination was acquired, tissue residue values (Objectives or Guidelines) cannot be allocated “warning” or “trigger” status within the LWMP process. Unequivocal linkages between tissue concentrations and specific discharges cannot always be established. However, tissue residue values are allocated “cautionary” status due to their importance in establishing health at higher trophic levels, and will therefore be considered as and where feasible.

Site specific Objectives and Provincial Guidelines represent a limited subset of all chemical constituents potentially present in the aquatic environment. A number of studies are taking place to address other criteria which might be of environmental relevance. The adaptive and dynamic nature of the “cautions, warnings and triggers” process provides the flexibility necessary for the introduction of new and relevant information that may develop through other studies and initiatives such as the MWLAP-sponsored program regarding PCBs in Harbour seals currently being carried out by Dr. Peter Ross (IOS). Other GVRD programs and external studies jointly provide critical supportive information. The Environmental Monitoring Committee (EMC) has a critical role in the process; it can introduce, highlight and discuss new research and can advise the GVRD to undertake a given study or consider management action.

6.3 CONCLUSIONS

The cautions, warnings and triggers process has been developed as required by the Minister of Water, Land and Air Protection in her approval of the LWMP in April of 2002. This document will be submitted to the provincial ministry by January 31st, 2004 as per the condition in the Minister's Letter of Approval, and as the culmination of an intense four year effort to develop the various components of such a process. Under the auspices of the Liquid Waste Management Plan, the GVRD has put in place a funded program of initiatives consisting of a number of components critical to the successful undertaking of the Cautions, Warnings and Triggers Process. These components include the relevant receiving environment monitoring programs, collaborative ambient monitoring programs, a condition seven program and the requirement for various special studies and initiatives.

The workshops of 2000 and 2001 demonstrated that monitoring programs able to detect small levels of effects on the benthic biota in the receiving environment could be established. Furthermore, it was demonstrated that these measured effects were statistically significant and could subsequently be measured on a reproducible basis over the following years. This has formed the cornerstone of the cautions, warnings and triggers process. Further compartments have also been added to this framework; namely the water column, sediment and tissue residue compartments. For consideration of these compartments, the site-specific Water Quality Objectives and the Provincial and Federal Guidelines have been taken as yardsticks of ecosystem integrity. Guidelines have been associated with relevant cautions and Objectives have been associated with warnings and triggers.

However, as presented in the document, the interpretation of these factors is often complex and must be undertaken in a complex framework relevant to the interactions of a given ecosystem. This process has been placed before the Environmental Monitoring Committee over a period of five months, by way of sequential presentations on the methodologies to be applied to each of the compartments. The members of the Environmental Monitoring Committee have critiqued the process leading to various revisions and amplification of the process to ensure that the critical components are captured with defensible methodologies. Having said this, it is recognized that a process such as this is a living process that must be sensitive to the changing scope of scientific knowledge and consequently dynamic and adaptive in nature.

Some members of the committee expressed concerns that the document would become carved in stone at the time of its submission to the Provincial Minister. The nature of the document prevents this possibility because it is based upon scientific approaches. As science evolves, so will the process. However, the science-based process developed in the document does require concrete scientific investigation and interpretation processes to be followed. Any management actions arising out of this process are therefore also bound by this same commitment to a scientifically based and defensible decision-making process.

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